U.S. Department
of Transportation
National Highway
Traffic Safety
Administration

NHTSA
People Saving People
http://www.nhtsa.dot.gov

DOT HS 808 499

June 1995

Final Report

Run-Off-Road Collision Avoidance Countermeasures Using IVHS Countermeasures

TASK 2

Volume 1: Technical Findings

Contracting Officer's Technical Representative's Precis

This report provides a basis for disseminating the preliminary contract results on a timely basis resulting in the information being available before the contract final reports are produced. Research performed during the remainder of the contract may support and/or modify the results, therefore, the material contained in this report should not be consider to be final. The current schedule calls for the completion of this research project by the third quarter of 1999.

Technical Report Documentation Page

I Report No	2 Government Accession No.	3 Recipients's Catalog No.
DOT HS 808 499		

4 Title and Subtitle	5 Report Date
Run-Off-Road Collision Avoidance Counter-measures Using IVHS Countermeasures Task 2 Final Interim Report Volume 1: Technical Findings	June 7, 1995 6 Performing Organization Code
7 Authors(s) J.A. Pierowiez, D.A. Pomerleau, D.L. Hendricks, E.S. Bollman N.J. Schmitt	8 Performing Organization Report No.
9 Performing Organization Name and Address Robotics Institute Carnegie Mellon University 5000 Forbes Avenue Pittsburgh, PA 15213	10 Work Unit No. (TRAIS) code 11 Contract of Grant DTNH22-93-C-07023
12 Sponsoring Agency Name and Address National Highway Traffic Safety Administration **400** Seventh Street SW. Washington, DC 20590	13 Type of Report and Period Covered Final Report 11-94 to 6-95 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The Run-Off-Road Collision Avoidance Using IVHS Countermeasures program is to address the single vehicle crash problem through application of technology to prevent and/or reduce the severity of these crashes.

This report describes and documents the analysis sequence conducted in Task 2 to achieve the following objectives:

* Establish Collision Taxonomy - The run-off-road collision population is to be classified in subsets that provide a basis for identifying opportunities for intervention in the sequence of events leading to a crash.

* Develop Functional Goals - On the basis of the consequences and factors that precede run-off-road crash subsets, determine functional goals that will eliminate or mitigate the severity of these crashes.

17. Key Words	18 Distribution Statement
Run-Off-Road Collision Avoidance Single Vehicle Roadway Departure Collision Taxonomy Functional Goals	Document is available to the public through the National Technical Information Service, Springfield, VA 22 16 1

19 Security Classif. (of this report)	20 Secirotu Classif (of this page)	21 No of Pages	22 Price
Unclassified	Unclassified	127	$169,531

Form DOT F1700.7 (S-72)

Reproduction of completed page authorized

Forward

The Run-Off-Road Collision Avoidance Using IVHS Countermeasures program is to address the single vehicle crash problem through application of technology to prevent, and/or reduce the severity of, these crashes. The prime contractor for this effort is Carnegie Mellon University (CMU) operating under Contract No. DTNH22-93-C-07023 Members of the project team include Battelle Memorial Institute, Calspan Corporation, and the University of Iowa.

The program consists of a sequence of nine related tasks to be completed in three distinct program phases. Phase I of this effort is currently fully funded and is comprised of the first four program tasks. Primary task completion responsibility has been assigned to individual team members with. Calspan conducting Tasks 1 and 2, CMU conducting Task 3, and Battelle conducting Task 4. As prime contractor, CMU provides guidance and oversight to all subcontractor effort.

The Task 1 report has been completed and approved. This report describes and documents the analysis sequence conducted in Task 2 to achieve task objectives. These objectives may be summarized as follows:

- Establish Collision Taxonomy - The run-off-road collision population is to be classified in subsets that provide a basis for identifying opportunities for intervention in the sequence of events leading to a crash.

- Develop Functional Goals - On the basis of the consequences and factors that precede run-off-road crash subsets, determine functional goals that world eliminate, or mitigate the severity of, these crashes.

A major finding of the Task 1 engineering analysis sequence was that cases grouped on the basis of causal factors resulted in crash subsets with similar preexisting conditions, crash circumstances/events, and driver actions. This finding was extended to the Task 2 effort where the taxonomy development effort focused on describing the relative time frames associated with roadway departures in each of the causal factor groups previously identified. The taxonomy was successfully developed and applied to the clinical sample of NASS CDS cases assembled for the Task 1 effort. These available time frames were then used in conjunction with other crash subset characteristics to develop practical functional goals for potential countermeasures.

Technical results from the Task 2 analysis sequence will be utilized in subsequent tasks to develop test plans for countermeasure technologies (Task 3) and to develop computer simulation models to determine countermeasure effectiveness (Task 4). In addition, it is anticipated that this volume and other support volumes will function as a resource reference for Phase II and Phase III tasks.

Table of Contents

Table of Contents
(Cont.)

Table of Contents
(Cont.)

Table of Contents
(Cont.)

List of Tables

List of Tables
(Cont.)

List of Figures

List of Figures
(Cont.)

List of Figures
(Cont.)

List of Figures
(Cont.)

1.0 Introduction

Single vehicle run-off-road target crashes (i.e., crashes applicable for this effort) represent the most serious crash problem within the national crash population. Analysis of the 1992 NASS GES file, conducted for the Task 1 report indicated that approximately 1.2 1 million police-reported crashes of this type occurred in that year. This number represented approximately 20.1 percent of the GES file crash. In addition, more than 520,000 vehicle occupants were injured in run-off-road target crashes in 1992 and this level of injury represented approximately 36.8 percent of the injured occupants in the GES file. In a similar manner, the 14,031 fatalities sustained in run-off-road crashes (FARS data) represented approximately 41.5 percent of the 33,846 in-vehicle fatalities that occurred in 1992. Thus, in terms of injury frequency and severity, the run-off-road target crash population is overrepresented.

The Run-Off-Road Collision Avoidance Using IVHS Countermeasures program has been developed to address this crash problem through application of technology to prevent, or reduce the severity of, these crashes. Advances in sensor design and data transmission/processing capabilities over the past decade allow collection and processing of extensive data sets obtained from the vehicle's operating environment. In addition, support technologies such as the Global Positioning System (GPS) permit the positions of vehicles to be determined with an increasing degree of accuracy. Application of these technologies and other emerging technologies is an integral part of a program intended to dramatically improve vehicle safety. This program, broadly titled Intelligent Vehicle Highway Systems (IVHS), will address the run-off-road crash problem and a fairly broad spectrum of other crash types.

The current program consists of a sequence of nine related tasks to be completed in three distinct program phases. Phase I of this effort is fully funded and is comprised of the four tasks summarized below:

- Task l: Thoroughly Analyze the Crash Problem
- Task 2: Establish Functional Goals
- Task 3: Conduct Hardware Testing of Existing Technologies
- Task 4: Develop Preliminary Performance Specifications Based on Critical Factors and Models of Crash Scenarios

The Phase I work flow is linear in nature in that the output of one task is utilized as an input to the next successive task and to subsequent tasks. In Task 1, for example, data analyses were conducted to determine the circumstances associated with run-off-road collisions and the causal factors or reasons why these crashes occurred. Engineering evaluations were also completed to establish the dynamic states of involved vehicles and the specific scenarios that were associated with these crashes. These results were carried forward to Task 2 where a taxonomy was developed to classify the run-off-road scenarios in terms of the relative length of departure time associated with each of the causal factor groupings. The latter information was directly used as a basis to develop practical functional goals for potential countermeasures. Task 2 results will be used in Task 3 to develop appropriate test plans and test evaluation criteria and will be used in Task 4 to conceptualize countermeasure systems. The conceptualized systems will then be evaluated via mathematical modeling to determine the probable effectiveness of each concept in terms of eliminating or reducing the severity of run-off-road crashes. These results, in turn, will be utilized in the subsequent effort to develop preliminary performance specifications for countermeasure systems.

Subsequent phases of this program will continue the development sequence. For example, in Phase II the contract team will perform state-of-the-art technology reviews and design test bed systems. The test bed systems will be evaluated in Phase III and preliminary performance specifications, initially developed in Task 4, will be modified as appropriate.

The analysis sequence conducted for Task 2 has been completed. The focus of this report is description and documentation of the analysis sequence and analysis results. Design implications of these results are also addressed. The report format and section content are as follows:

Section 2.0 Approach

This section describes the methodology that is applied to the Task 2 analysis sequence. This sequence incorporates the groupings of similar situation trees that resulted from aggregating cases by causal factor during the Task 1 Engineering Analysis. A collision taxonomy is developed to categorize roadway departure times within the causal factor groups. The qualitative ratings provided by the taxonomy are then quantified by incorporating computed departure times derived from the NASS CDS case sample assembled for Task 1. The common characteristics within causal factor groups and these departure time assessments are then used to develop practical functional goals for each group.

Section 3.0 Development of Collision Taxonomy

This section describes the methodology developed to further evaluate the 20 1 NASS CDS cases utilized in Task 1. A brief review of the situation tree groupings established in Task 1 is provided. Since the characteristics of these groups are fairly distinctive, the project staff believes that it is essential to examine available time frames more closely. The early focus of the taxonomy development is, therefore, directed at providing a qualitative assessment of the available intervention time frames between the point where the subject vehicle begins moving from its precrash travel position and the point where the vehicle departs the roadway. These qualitative assessments are then supplemented with quantitative assessments that are computed for those NASS cases containing sufficient data for this purpose. The quantitative time estimates verify the qualitative framework established by the taxonomy and are extended to the causal factor groupings via this mechanism.

Section 4.0 Development of Countermeasure Functional Goals

This section describes development of countermeasure functional goals for each of the causal factor groups based on the characteristics of each group and available intervention time frames. The development sequence for each causal factor group is discussed in detail.

Causal factor groups requiring approaches which are beyond the scope of the current effort or are being addressed in other specification programs are clearly identified.

Section 5.0 Issues Related to Functional Goal Utilization

The sets of functional goals developed in Section 4.0 are compared to establish the degree of similarity that exists between sets. Sets with similar groupings of functional goals are merged to achieve broader applicability of the common sets. Design implications/issues associated with these merged sets are addressed to ensure as much detail as possible for the resulting goals.

Section 6.0 Preliminary Functional Goals For Run-Off-Road Countermeasure Systems

This section presents the final sets of preliminary functional goals developed for run-off-road countermeasures. Details of potential countermeasure approaches that incorporate these goals are provided. Functional diagrams depicting countermeasures functions and processes are also presented.

Section 7.0 Summary and Conclusions

A summary of the process used to generate the sets of functional goals for run-off-road collision avoidance countermeasures is provided. The functional goal sets that are the output of this process are also summarized as are major conclusions deriving from this effort.

2.0 Approach

Successful development of countermeasures for run-off-road crashes requires a thorough understanding of this crash problem type. The requisite insight was established in the Task 1 analysis sequence which examined the circumstances/events associated with run-off-road crashes, crash configurations, frequency of occurrence, and the specific reasons why these crashes occur (i.e., causal factors). The causal factor profile was established for run-off-road crashes by performing a clinical analysis of 201 hard copy cases selected from the National Accident Sampling System (NASS) Crashworthiness Data System (CDS). Analysis results indicated that the causal profile was comprised of six major factors. These causal factors and the relative proportion of the sample in which the factors were applicable may be summarized as follows:

Causal Factor		Weighted Percent
Driver Inattention		12.66
Relinquished Steering Control		20.07
Evasive Maneuver		15.68
Lost Directional Control		15.96
Vehicle Failure		3.64
Vehicle Speed		31.99
	Total	100.00

In addition to determining causal factors and crash characteristics, the project staff also completed an engineering analysis of the clinical sample to establish the dynamic scenarios associated with these crashes. The data entry/reduction format used for this effort is provided in Figure 2-1. Note that individual case dynamic scenarios were represented as situation trees. When the individual situation trees were aggregated on the basis of similar responses, it was found that the resulting groupings coincided with causal factor designations. This was an important finding since the causal factor designation, in addition to indicating the specific reasons why crashes occurred, could now also be assumed to imply an identifiable set of pre-existing conditions and on/off-road dynamic states. These situation tree characteristics are reviewed in Section 3.0.

While the Task 1 analysis sequence forms the foundation for the development of run-off-road countermeasures, the sequence is insufficient to permit complete definition of countermeasure concepts. A key parameter that is lacking at this point is an indication of the time frame available for potential countermeasures to detect that roadway departure is occurring or is imminent and to then issue a warning. This parameter will be added to information derived from Task 1 as part of the collision taxonomy development sequence scheduled for Task 2. Task 1 data and the taxonomy will then be used to develop sets of functional goals for run-off-road collision avoidance countermeasures.

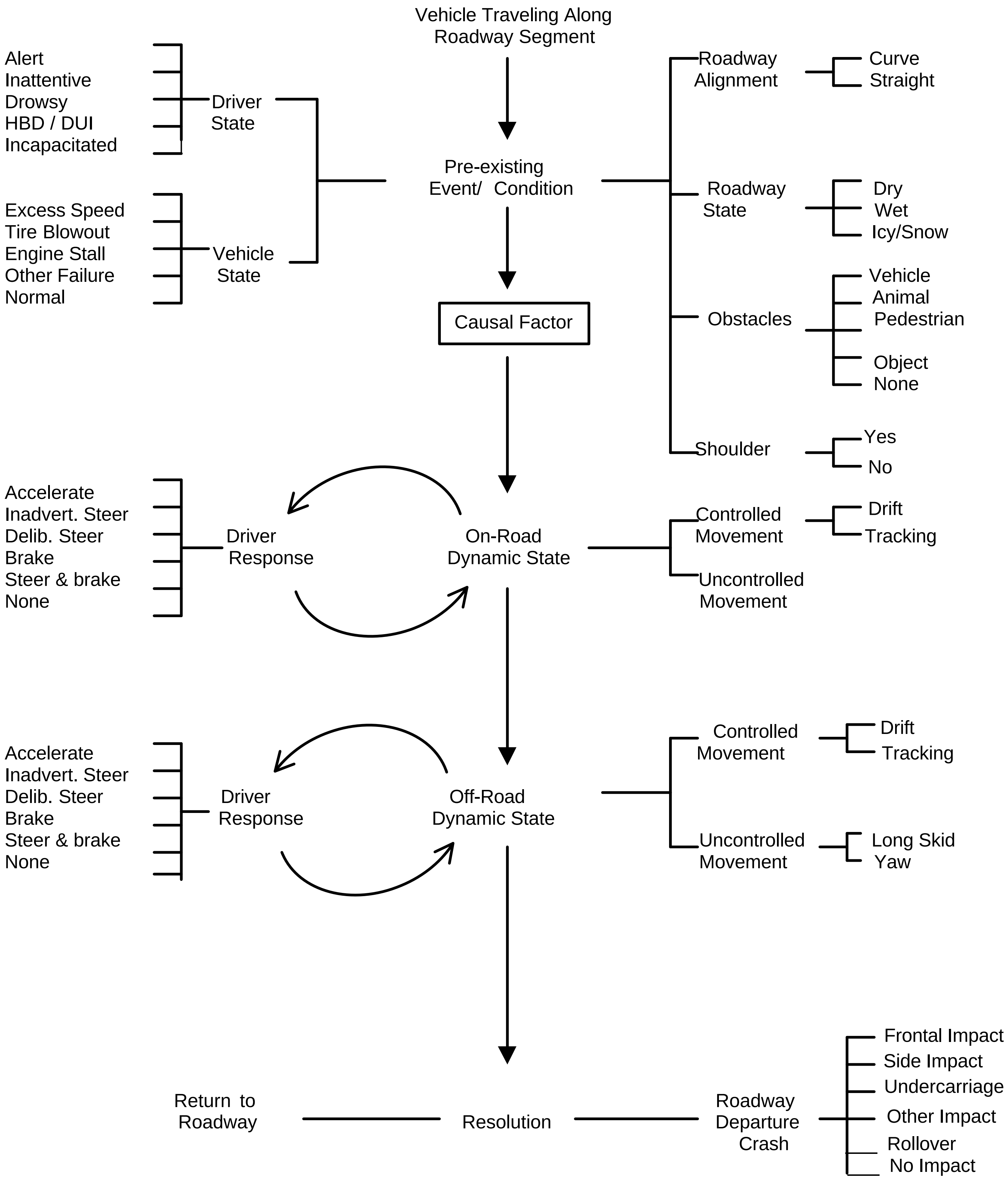


Figure 2-1 VEHICLE DYNAMIC SCENARIO

Functional goals are defined as data, warnings, or actions acquired or performed by vehicle-based or infrastructure-based equipment that could be presented to the driver to achieve crash avoidance. Specific functional goals may include the ability of vehicle-based equipment to process available information and initiate action to prevent a collision and/or roadway departure.

The sequence that is followed in this report to develop sets of functional goals is illustrated in Figure 2-2. The groupings of similar dynamic scenarios established in Task 1 are used as the basis for the development sequence. As indicated previously, within these groupings of similar dynamic scenarios there is a high degree of consistency noted for crash circumstances including pre-existing conditions, on-/off-road vehicle dynamic states, and driver responses associated with these states.

Division of the clinical sample into groups of similar scenarios also provides an efficient means for examination of available time frames in which collision avoidance objectives may be achieved. It is likely, for example, that these groups of similar cases will have similar intervention time frames. In a similar manner, it is also likely that fairly disparate time frames will be noted between the groups of similar scenarios. For these circumstances, differing countermeasure approaches and differing functional goals sets are likely to be required.

The final collision taxonomy developed during Task 2 includes an assessment of available time frames. Initially, taxonomy development focuses on providing qualitative assessments of available time for each case contained in the clinical sample, These qualitative assessments are then quantified using computed time frames from those cases in the clinical sample containing sufficient data to successfully complete the associated calculations. A preliminary review of the sample cases, indicated that 102 of the 201 crashes in the run-off-road sample could be used for this purpose. Once the calculations are completed, average time frames are established for each causal factor grouping of similar dynamic scenarios.

Using available information describing intervention time frames, pre-existing conditions, vehicle dynamic states, and associated driver responses, the project staff developed sets of functional goals that could be utilized to prevent crashes in each grouping of similar crashes. It was fully expected that differing goal sets for the causal factor groups would contain many individual goals that were similar. For example, it is likely that determining vehicle position on a roadway segment would be an individual goal that is common to all of the functional goal sets. One or two common goals of this type does not necessarily imply a common countermeasure approach. Following completion of the functional goal development activity, however, the project staff reviewed all of the resulting functional goal sets for the purpose of determining common approaches. Similar sets of goals that implied common approaches were then merged to establish the final sets of goals. In the ideal situation, this process would have resulted in a single set of functional goals suited to all possible run-off-road crashes. The latter circumstance was unlikely at best and it was anticipated that the final product would involve multiple sets of functional goals that were directed at specific subsets of run-off-road crashes.

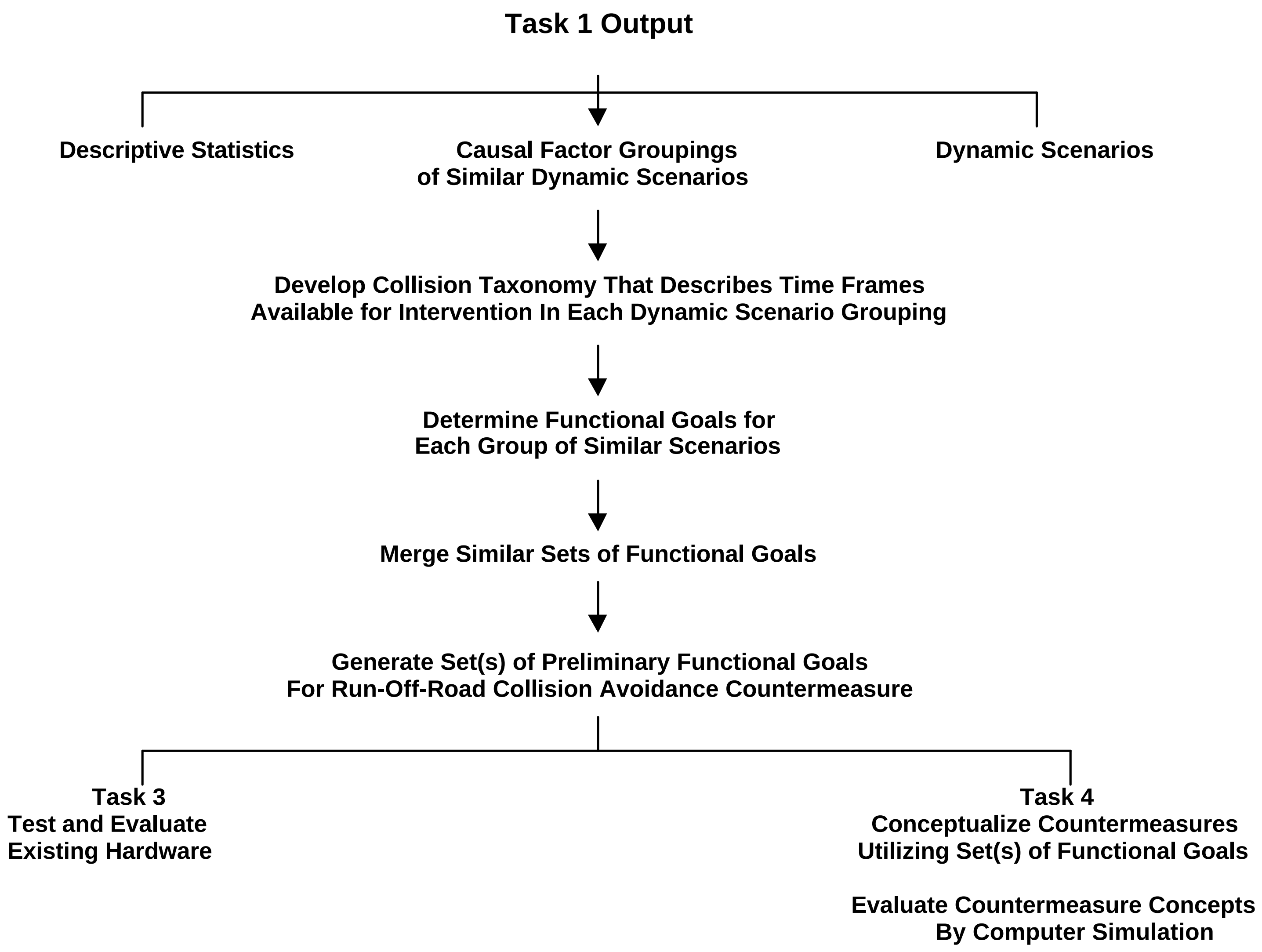


Figure 2-2 FUNCTIONAL GOAL DEVELOPMENT SEQUENCE

The multiple sets of functional goals deriving from Task 2 will be carried forward into Task 3 and Task 4. In Task 3, these sets will be used to develop hardware test plans and test evaluation criteria. These same sets of goals will also be used to conceptualize countermeasure concepts in Task 4. These concepts will then be further evaluated via modeling in this task to determine the probable effectiveness of each countermeasure approach. Further compression/merging of functional goal sets may occur after modeling results are available.

3.0 Development of Collision Taxonomy

A collision taxonomy for run-off-road crashes groups the clinical sample into categories that exhibit similar dynamic characteristics, similar intervention opportunities, and similar intervention time frames Portions of the taxonomy were developed as part of the Task 1 effort where groups of similar dynamic scenarios were established. These groupings are reviewed in the subsection which follows. Qualitative and quantitative assessments of available intervention time frames are provided in subsequent subsections and the final taxonomy is then presented and evaluated.

3.1 Review of Dynamic Groupings

As indicated in the engineering analysis discussion provided in the Task 1 Interim Report, dynamic scenario descriptions delineate existing conditions related to crash occurrence (driver state, vehicle state, environmental conditions), driver/vehicle actions or events, driver corrective actions initiated to avoid the crash, and vehicle responses to corrective actions. These descriptions may be represented as situation trees. The specific situation tree/data reduction format developed for this effort is illustrated in Figure 2-2.

Situation trees were developed for each case in the clinical sample. Individual copies of the trees are provided in Volume II of the Task 1 Interim Report. These trees were subsequently analyzed to determine characteristics associated with groups of similar trees. Several approaches to categorizing/grouping similar situation trees were explored and subsequently dropped. For example, groupings based on roadway alignment, roadway state, and on-road dynamic state were examined. Variations within groups established on this basis were substantial and these attempts to superimpose a distinct structure to the grouping process were abandoned.

When situation trees were grouped solely on the basis of having similar responses in each of the branches contained in the data reduction formats, it was noted that the resulting groups or subsets of formats closely paralleled causal factor designations. At that point, a decision was made to group the trees by causal factor designation and to examine similarities and variances within these groupings.

An example summary situation tree for the Driver Inattention causal factor group is provided in Figure 3-l. This summary format shows the distribution of responses for each branch of the situation trees comprising this group. A complete set of summary situation trees have been reproduced from the Task 1 report and are provided as Appendix A of this report. The corresponding discussions of the characteristics of these summary trees have also been included in Appendix A.

Tabulations of the most frequently occurring variables within each causal factor group were provided in Tables 5-47 and 5-48 of the Task 1 Interim Report. Those tables have been reproduced and are provided as Tables 3-l and 3-2 on the following pages. Tables 3-l describes pre-existing conditions within each causal factor group and Table 3-2 describes dynamic states and the result of these states (e.g., impact type) within each causal factor group. Major points derived from these tables may be summarized as follows:

Causal Factor: **Driver Inattention**

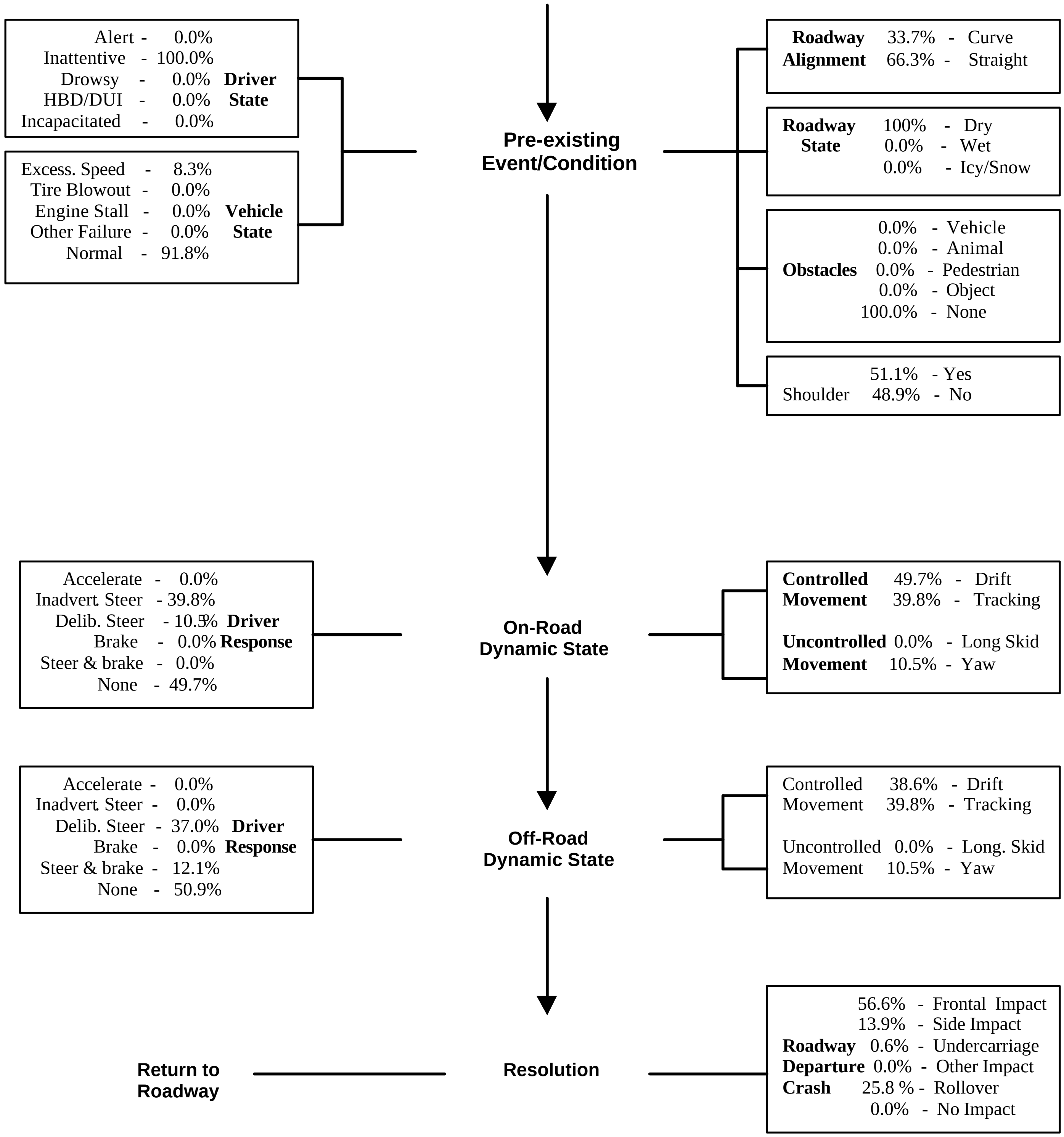


Figure 3-1 VEHICLE DYNAMIC SCENARIO ANALYSIS - DRIVER INATTENTION

Table 3-1

- ***Driver State***

  In three of the causal factor groups, the predominant driver state is alert. These groups are Evasive Maneuver (84.5 percent), Lost Directional Control (99.2 percent), and Vehicle Failure (100.0 percent). The predominant state for the Driver Inattention group is inattention (100.0 percent). In the Relinquished Steering Control group, there are two primary states (HBD/DUI- 58.9 percent and Drowsy - 36.0 percent). The Vehicle Speed group also has two primary states (Alert - 59.5 percent and HBD/DUI - 40.3 percent).

- ***Vehicle State***

  In four of the causal factor groups, the predominant vehicle state is normal. These groups are Driver Inattention (91.8 percent), Relinquished Steering Control (98.3 percent), Evasive Maneuver (100.0 percent), and Lost Directional Control (96.1 percent). A variety of vehicle failures dominate the distribution for the Vehicle Failure group and virtually all crashes in the Vehicle Speed group involve excessive speed.

- ***Roadway Alignment***

  The causal factor groups are evenly split between straight and curved segments. Curved segment locations dominate the distribution for the Relinquished Steering Control (55.7 percent), Vehicle Failure (79.8 percent), and Vehicle Speed (58.4 percent) groups. Straight segment locations dominate the distributions for the Driver Inattention (66.3 percent), Evasive Maneuver (66.8 percent), and Lost Directional Control (53.3 percent) groups.

- ***Roadway State***

  The dry surface condition is the most prevalent condition in five of the causal factor groups. Icy/snow conditions (56.6 percent) and wet surfaces (34.8 percent) dominate the distribution for the Lost Directional Control group.

- ***Obstacles***

  Obstacles are typically not involved in the crash sequences associated with five of the causal factor groups. The presence of vehicles (67.2 percent) and animals (32.8 percent) in the driver's intended path of travel dominate the distribution for the Evasive Maneuver group.

- ***Shoulder***

  Most crashes occur in locations that have an adjacent shoulder for the Driver Inattention (5 1.1 percent), Evasive Maneuver (69.6 percent), Lost Directional Control (65.5 percent), and Vehicle Speed (72.4 percent) groups. The no shoulder circumstance dominates distributions for the Relinquished Steering Control (76.3 percent) and Vehicle Failure (66.2 percent) groups.

Table 3-2

- ***On-Road Driver Response***
  In four of the six groups the most frequent driver response involves no corrective action. These groups are Driver Inattention (49.7 percent), Relinquished Steering Control (85.3 percent), Vehicle Failure (66.2 percent), and Vehicle Speed (27.5 percent). In the Evasive Maneuver and Lost Directional Control groups, deliberate steering actions (56.1 and 40.4 percent, respectively) are the most frequent response.

- ***On-Road Vehicle Response***
  Drift movements are the most frequent responses in three groups; Driver Inattention (49.7 percent), Relinquished Steering Control (85.3 percent), and Vehicle Failure (64.2 percent). Tracking movements are the most frequent responses in the Evasive Maneuver (77.6 percent) and Vehicle Speed (41.8 percent) groups. Yaw movements dominate the distribution for the Lost Directional Control (69.5 percent) group.

- ***Off-Road Driver Response***
  The most frequent off-road ***driver*** response is to initiate no corrective action in four of the causal factor groups; Driver Inattention (50.9 percent), Relinquished Steering Control (80.9 percent), Lost Directional Control (45.0 percent), and Vehicle Failure (66.2 percent). Deliberate steering actions dominate the distribution for Evasive Maneuver (47.8 percent) and braking actions dominate the distribution for Vehicle Speed (33.9 percent).

- ***Off-Road Vehicle Response***
  Yaw movements are the most frequent responses in four groups; Driver Inattention (39.1 percent), Evasive Maneuver (55.6 percent), Lost Directional Control (61.6 percent), and Vehicle Speed (40.6 percent). Drift movements are the most frequent responses in two groups; Relinquished Steering Control (65.9 percent) and Vehicle Failure (64.2 percent).

- ***Roadway Departure Crash Type***
  The frontal impact configuration is the most frequent impact type in five of the six groups; Driver Inattention (59.6 percent), Relinquished Steering Control (77.2 percent), Evasive Maneuver (38.1 percent), Vehicle Failure (74.3 percent), and Vehicle Speed (58.8 percent). Rollovers are the second most frequent configuration in four of these groups; Driver Inattention (25.8 percent), Evasive Maneuver (24.3 percent), Vehicle Failure (23.7 percent), and Vehicle Speed (16.3 percent). Side impacts are the most frequent configuration in the Lost Directional Control (42.7 percent) group.

The engineering analysis conducted to derive the information reported in Tables 3-l and 3-2 demonstrated that there were distinctive subgroups within the run-off-road crash population. The information reported in these tables crystallizes the subgroups on the basis of causal factor designation and defines major characteristics of each group.

Table 3-l
Pre-existing Conditions Within Causal Factor Groups

Crash Characteristics	Causal Factor Groups					
	Driver Inattention	*Relinquished Steering Control*	*Evasive Maneuver*	*Lost Directional Control*	*Vehicle Failure*	*Vehicle Speed*
Driver State						
Alert			84.5	99.2	100.0	59.5
Inattentive	100.0					
Drowsy		36.0				
HBD/DUI		58.9				40.3
Incapacitated						
Vehicle State						
Excess Speed						100.0
Tire Blowout						
Engine Stall					64.2	
Other Failure					25.7	
Normal	91.8	98.3	100.0	96.1		
Roadway Alignment						
Curve		55.7			79.8	58.4
Straight	66.3		66.8	53.3		
Roadway State						
Dry	100.0	86.4	60.0		100.0	64.9
Wet				34.8		
Icy/Snow				56.6		
Obstacles						
Vehicle			67.2			
Animal			32.8			
Pedestrian						
Object						
None	100.0	100.0		100.0	100.0	95.5
Shoulder						
Yes	51.1		69.6	65.5		724
No		76.3			66.2	

Table 3-2
Dynamic State Within Causal Factor Groups

Crash Characteristics	Causal Factor Groups					
	Driver Inattention	*Relinquished Steering Control*	*Evasive Maneuver*	*Lost Directioal Control*	*Vehicle Failure*	*Vehicle Speed*
On-Road Driver Response						
Accelerate						
Inadvertent Steering	39.8					
Deliberate Steering			56.1	40.4	17.6	26.8
Brake						
Steer + Brake			41.1			
None	49.7	85.3		33.5	66.2	27.5
On-Road Vehicle Response						
Drift	49.7	85.3			64.2	
Tracking	39.8		77.6			41.8
Longitudinal Skid				28.1		
Yaw				69.5	23.7	29.9
Off-Road Driver Response						
Accelerate						
Inadvertent Steering						
Deliberate Steering	37.0	17.2	47.8		15.6	29.0
Brake				24.1		33.9
Steer + Brake			39.1			
None	50.9	80.9		45.0	66.2	
Off-Road Vehicle Response						
Drift	38.6	65.9			64.2	
Tracking			35.0			37.4
Longitudinal Skid				28.1		
Yaw	39.1	19.9	55.6	61.6	33.8	40.6
Roadway Departure Crash Type						
Frontal Impact	59.6	77.2	38.1	39.7	74.3	58.8
Side Impact		19.6		42.7		
Undercarriage						
Other Impact						
Rollover	25.8		24.3		23.7	16.3
No Impact						

While useful this information is insufficient to develop complete sets of functional goals. Additional information necessary for this purpose includes an assessment of the available intervention time frames (i.e., roadway departure times). Qualitative and quantitative assessments of these time frames are developed for each causal factor group in the next two subsections, respectively.

3 3 Qualitative Assessment of Available Intervention Time Frames

One of the first problems considered by the project staff when developing time related assessments for the clinical sample established in Task 1 involved recognition of data limitations. Specifically, there was insufficient data in a number of the cases in the sample to permit quantitative assessments of time frames for every case. At that point, the staff elected to develop a two stage classification scheme. In the initial stage a qualitative assessment of roadway departure times (defined as the elapsed time between the point where the subject vehicle began moving from its pre-crash travel lane position and the point where the first wheel of this vehicle exited the roadway) would be provided for each case in the sample. These qualitative assessments would then be refined in the second stage using computed time frames established for those sample cases containing sufficient data for this purpose.

A number of elements were considered for the qualitative classification scheme. After reviewing a cross-section of cases, however, the project staff selected a core group of variables which appeared to have the most significant influence on the length of roadway departure times as defined above. These variables were:

- Roadway geometry (i.e., straight segment versus curved segment) and within curved segments the direction of curvature (i.e., left curve versus right curve).
- Direction of roadway departure (i.e., left departure versus right departure).
- Pre-crash travel lane (i.e., specific lane the subject vehicle was traveling in prior to initiation of the departure trajectory).

The classification scheme resulting from the above elements is illustrated in Figure 3-2. Eight classifications are required to provide complete coverage of curved segments due to differences in the direction of curvature (i.e., left versus right) and these eight classifications can be reduced to four comparable classifications in circumstances involving straight segments. Specific combinations of elements result in four classifications (1,2,7, and 8) where the elapsed time interval between the point where the subject vehicle begins moving from its pre-crash travel lane position and the point of roadway departure should be relatively long. Similarly, other combinations result in four classifications (3,4,5, and 6) where the elapsed time frame between these same two points should be relatively short.

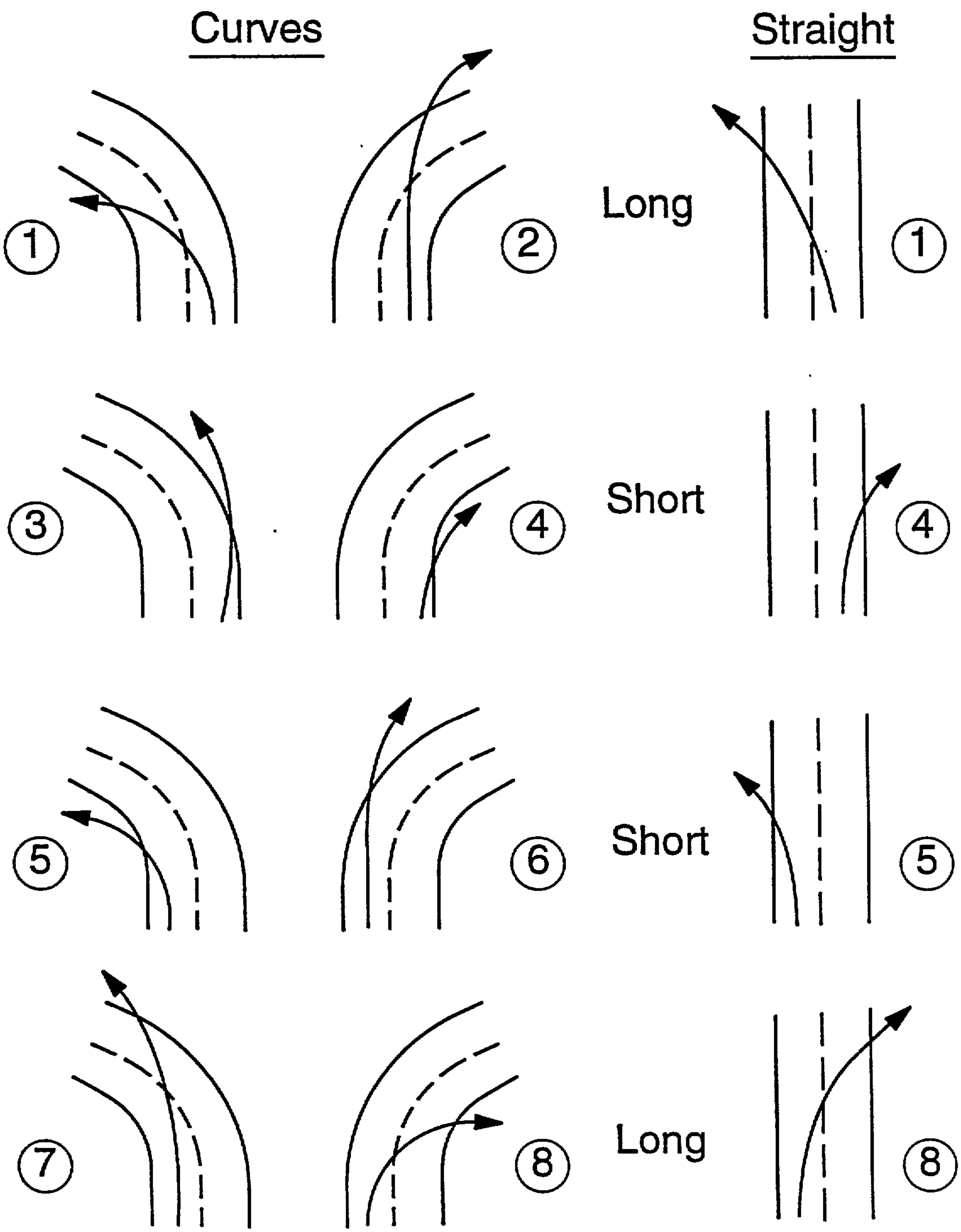


Figure 3–2 QUALITATIVE ASSESSMENT OF ROADWAY DEPARTURE TIME

The distribution of departure time designations for the clinical sample is provided in Table 3-3. These qualitative assessments are tabulated for both curved and straight roadway segments within each causal factor group. Assessments indicating relatively short departure times predominate the distributions for the Driver Inattention (88.5 percent), Evasive Maneuver (77.8 percent), Relinquished Steering Control (90.4 percent), and Vehicle Failure (76.0 percent) causal factor groups. This trend is reversed in the Lost Directional Control and Vehicle Speed causal factor groups where designations indicating relatively long roadway departure times (71.2 percent and 57.1 percent, respectively) predominate.

It should be noted the departure time estimates provided by this qualitative classification scheme do not include a number of key elements such as vehicle velocity, the angle of the departure trajectory, or the presence of additional travel lanes. Each of these elements can have a significant affect on the length of the actual departure time. For example, if all other factors are identical, vehicles traveling at high velocities will have significantly shorter departure times than vehicles traveling at lower velocities. Similarly, vehicles departing the roadway at high departure angles will have significantly shorter departure times than vehicles departing the roadway at shallow angles. In addition, current classifications of long departure times can also vary significantly if the subject vehicle is crossing more than the one additional lane shown in Figure 3-2. Factors of this type are included in the computed time frames developed in the following subsection. To reduce the extent of variability that is common to these calculations, mean values are used in the final classification scheme to represent long and short departure times within each causal factor group.

3.3 Quantitative Assessment of Available Intervention Time Frames

A detailed review of the clinical sample was completed to determine the number of cases with sufficient data to allow computation of roadway departure times. Two primary criteria were used to select cases which could be used to develop reliable estimates. These criteria may be summarized as follows:

- Sufficient known points to reasonably establish on-and-off road trajectories - This was an essential requirement since it would be necessary to establish on-road travel distances and the approximate departure trajectory from the roadway.

- A reasonable indication of the subject vehicle's initial travel velocity - This information was required as an input to the TIMLIN program which was used to generate timeline histories for each case. During an initial review, the project staff found 32 cases which contained a clear indication of initial velocity (computed, police reported, or driver reported). In a subsequent review, conducted to expand the available pool of cases, the project staff identified an additional 70 cases where it appeared that a reasonable estimate of travel velocity could be provided if specific assumptions were made. These cases were added to the computation case pool. All required assumptions for these cases are documented in the support data volume assembled for this effort.

Table 3-3
Qualitative Departure Time Estimates
For Clinical Sample (201 Cases)

Causal Factor	Roadway Alignment	Departure Time (Long/Short) Weighted Percentage of Cases		Total
		Long	Short	
Driver Inattention	Curve	2.0%	98.0%	100.0%
	Straight	15.4%	84.6%	100.0%
	All	11.5%	88.5%	100.0%
Relinquished Steering Control	Curve	10.5%	89.5%	100.0%
	Straight	7.8%	92.2%	100.0%
	All	9.6%	90.4%	100.0%
Evasive Maneuver	Curve	2.6%	97.4%	100.0%
	Straight	31.5%	68.5%	100.0%
	All	22.2%	77.8%	100.0%
Lost Directional Control	Curve	64.0%	36.0%	100.0%
	Straight	74.2%	25.8%	100.0%
	All	71.2%	28.8%	100.0%
Vehicle Failure	Curve	0.0%	100.0%	100.0%
	Straight	54.5%	45.5%	100.0%
	All	24.0%	76.0%	100.0%
Vehicle Speed	Curve	53.0%	47.0%	100.0%
	Straight	68.9%	31.1%	100.0%
	All	57.1%	42.9%	100.0%
	Total	**37.7%**	**62.3%**	**100.0%**

The final sample of cases used to establish quantitative assessments of roadway departure times was comprised of the 102 cases meeting the requirements described above. For this sample, straight line projection techniques *were* used to establish the point where the subject vehicle began moving from its pre-departure travel position. Specifically, the vehicle's off-road trajectory was projected rearward in a straight line fashion to the point where it intercepted a straight line prolongation of the vehicle's on-road trajectory as shown in Figure 3-3. The intercept point was assumed to be the point where the subject vehicle began departing from its pre-crash on-road travel position. Travel distances were also measured in a straight line fashion. A very basic algorithm was then used to calculate departure times as follows:

$$\text{Time} = \frac{\text{distance}}{\text{velocity}} \times \text{conversion factor}$$

$$= \frac{\text{distance (m)}}{\text{velocity (km/hr)}} \times \frac{1\ \text{km}}{1000\ \text{m}} \times \frac{60\text{min}}{1\ \text{hr}} \times \frac{60\ \text{sec}}{1\ \text{min}}$$

$$= \frac{\text{distance (m)}}{\text{velocity (km/hr)}} \times 3.6$$

Tabulation results associated with aggregating individual case departure times are provided in Table 3-4. This table indicates mean values for long and short departure times on both curved and straight roadway segments within each causal factor group. Mean values are also provided for each causal factor group as a whole. In terms of mean values, the longest departure times are associated with the Driver Inattention (2.27 seconds), Vehicle Failure (1.84 seconds), and Relinquished Steering Control (1.82 seconds) causal factor groups. Within these three groups, the longest mean departure times are associated with curved roadway segments in the Driver Inattention (2.77 seconds) and Relinquished Steering Control (1.93 seconds) causal factors. At the opposite extreme, the shortest mean departure times are associated with the Evasive Maneuver (0.50 seconds) causal factor group and with departures from curved (0.37. seconds) and straight (0.54 seconds) segments within this group. The very short times associated with the Evasive Maneuver group are an expected result in that drivers in this category are attempting to avoid something in the roadway and are, therefore, deliberately steering off the roadway.

A second and somewhat obvious finding associated with Table 3-4 is that the overall mean value associated with the long departure time category (1.69 seconds) is significantly longer than the mean time associated with short departure time category (0.83 seconds). Again, this is an anticipated finding in that Table 3-4 merely provided quantitative assessments for the qualitative categories established in Section 3.2. Departure time estimates for each case in this computation sample are provided in Appendix B.

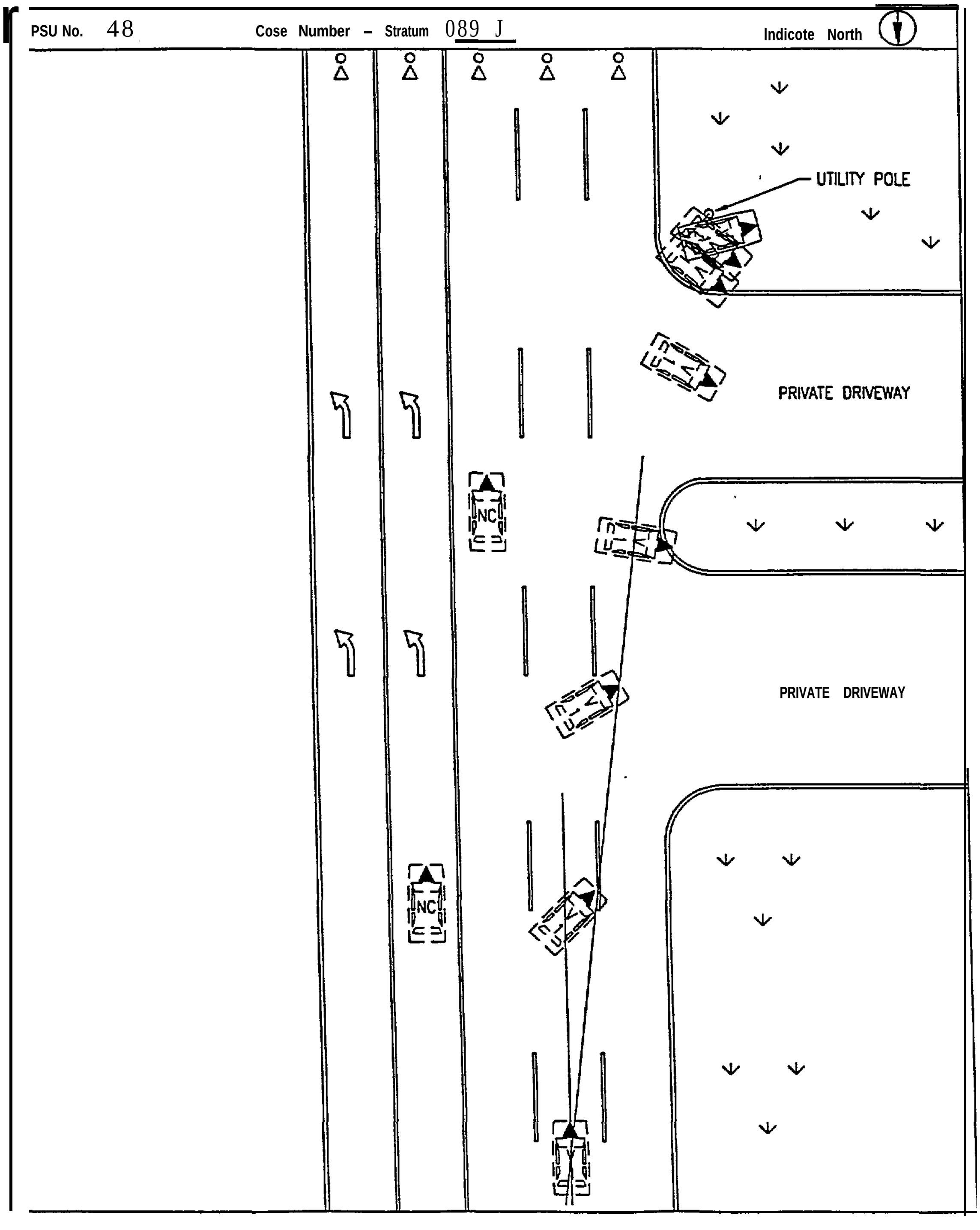


Figure 3-3 **RUN-OFF-ROAD COLLISION DIAGRAM SHOWING STRAIGHT LINE PROJECTION TECHNIQUE Case No. 48-089**

Table 3-4
Departure Time to Roadway Edge

Causal Factor	Roadway Alignment	Departure Time Roadway Edge	
		Mean Long Departure Time	Mean Short Departure Time
Driver Inattention	Curve	2.77	0.94
	Straight	2.03	0.94
	All	2.27	0.94
Relinquished Steering Control	Curve	1.93	0.89
	Straight	1.72	0.89
	All	1.82	0.89
Evasive Maneuver	Curve	#N/A	0.37
	Straight	1.28	0.54
	All	1.28	0.50
Lost Directional Control	Curve	1.17	#N/A
	Straight	1.26	1.05
	All	1.52	1.05
Vehicle Failure	Curve	#N/A	1.02
	Straight	1.84	0.57
	All	1.84	0.69
Vehicle Speed	Curve	1.56	0.75
	Straight	1.70	1.00
	All	1.63	0.81
	Total	**1.69**	**0.83**

In addition to computing departure times to the roadway edge, the project staff also computed departure times to the edge of the shoulder for those cases where there was a stabilized non-grass shoulder adjacent to the roadway departure edge. The reasoning here was that stabilized shoulder surfaces could be used to initiate trajectory recovery actions. A total of 62 cases in the 102 case sample had an adjacent stabilized shoulder. Mean departure times computed to the edge of the roadway (when there is no stabilized shoulder) or to the edge of the shoulder (when a stabilized shoulder is present) are provided in Table 3-5. The primary effect of including the shoulder area is to lengthen departure time estimates, however, the effect is not uniform. The sample average for long departure times increases from 1.69 seconds in Table 3-4 to 1.84 seconds in Table 3-5, whereas, the sample average for short departure times increases from 0.83 seconds in Table 3-4 to 1.20 seconds in Table 3-5. This result is associated with the departure angles of subject vehicles in the long and short departure time categories. Specifically, the mean shoulder width in the long departure time category is 1.6 meters and the comparable width for the short departure time category is 1.9 meters. The mean travel distances across these shoulder areas are 4.70 meters and 15.43 meters for the long and short departure time categories, respectively. These dimensions translate to mean departure angles of 19.9 degrees for the long departure time category and 7.1 degrees for the short departure time category.

The differences between the mean departure angles for the long and short departure time categories are logical and consistent with earlier findings. Subject vehicles in the long departure category have crossed at least one additional travel lane and therefore, have traveled longer distances than subject vehicles in the short departure time category. Although the initial stages of departure trajectories in both categories tend to be very shallow, this angularity tends to increase dramatically in the later stages of both categories. Because of their longer pre-departure travel distances, subject vehicles in the longer departure time category are in the later stages of their departure trajectories. Departure time estimates for each case in this computation sample (i.e., Shoulder/Roadway Edge) are provided in Appendix B .

A concern of the project staff with respect to time estimates generated by application of the straight line projection technique is that these estimates tend to be very conservative (i.e., understate available intervention time frames) and the effect of using this technique is not uniform across the causal factor groups. There is ample evidence that the largest degree of underestimation is associated with the Driver Inattention and Relinquished Steering Control groups. In both of these groups, early stages of subject vehicle roadway departure trajectories tend to be shallow arcs with very long radii. Due to this tendency, the project staff elected to reexamine these two groups and apply an algorithm that models the vehicle trajectory as a circular arc of constant radius. The calculation algorithm and the derivation of this algorithm are provided in Appendix C.

Application results using the circular arc algorithm are shown in Table 3-6. Note that there is a significant expansion of the mean departure time for three of the four categories examined. Specifically, the mean short departure time for the Driver Inattention group increases from 0.94 seconds in Table 3-4 to 2.12 seconds in Table 3-6. In a similar manner, the mean long departure time for the Relinquished Steering Control group increases from 1.82 seconds in Table 3-4 to 3.78 seconds in Table 3-6 and the mean short departure time for this same group increases from 0.89

seconds in Table 3-4 to 1.38 seconds in Table 3-6. The increase for the mean long departure time in the Driver Inattention group is relatively insignificant, increasing from 2.27 seconds in Table 3-4 to 2.36 seconds in Table 3-6. Departure time estimates derived with the circular arc algorithm for cases in the Driver Inattention and Relinquished Steering Control groups are provided in Appendix D.

Table 3-5
Departure Time to Roadway or Shoulder Edge

Causual Factor	Roadway Alignment	Departure Time Shoulder/Roadway Edge	
		Mean Long Departure Time	Mean Short Departure Time
Driver Inattention	Curve	2.77	1.81
	Straight	2.04	1.16
	All	2.28	1.30
Relinquished Steering Control	Curve	1.94	1.16
	Straight	1.98	1.37
	All	1.96	1.26
Evasive Maneuver	Curve	#N/A	0.81
	Straight	1.33	1.06
	All	1.33	1.01
lost Directional Control	Curve	2.12	#N/A
	Straight	1.54	1.45
	All	1.83	1.45
Vehicle Failure	Curve	#N/A	2.21
	Straight	1.84	0.82
	All	1.84	1.17
Vehicle Speed	Curve	1.73	1.12
	Straight	1.72	1.04
	All	1.73	1.10
	Total	**1.84**	**1.20**

The project staff believes that the time estimates provided in Table 3-6are a more accurate reflection of the roadway departure times and the available intervention time frames for these two causal factor groups. These time frames will, therefore, be substituted for the time frames shown for the Driver Inattention and Relinquished Steering Control groups in Table 3-4.

Table 3-6
Departure Time to Roadway Edge
Using Circular Arc Algorithm

Causal Factor	**Roadway Alignment**	**Departure Time - Roadway Edge**	
		Mean Long Departure Time	**Mean Short Departure Time**
Driver Inattention	Curve	2.91	2.02
	Straight	1.80	2.15
	All	2.36	2.12
Relinquished Steering Control	Curve	5.96	1.26
	Straight	1.60	1.50
	All	3.78	1.38
Evasive Maneuver	Curve	#N/A	#N/A
	Straight	#N/A	#N/A
	All	#N/A	#N/A
Lost Directional Control	Curve	#N/A	#N/A
	Straight	#N/A	#N/A
	All	#N/A	#N/A
Vehicle Failure	Curve	#N/A	#N/A
	Straight	#N/A	#N/A
	All	#N/A	#N/A
Vehicle Speed	Curve	#N/A	#N/A
	Straight	#N/A	#N/A
	All	#N/A	#N/A
	Total	**3.30**	**1.67**

Corresponding time frames computed with the circular arc algorithm to the edge of the roadway or to the edge of the shoulder for those cases having a stabilized shoulder adjacent to the departure lane are provided in Table 3-7. The same trend noted between Tables 3-4 and 3-5 is also apparent between Tables 3-6 and 3-7. Specifically, the most significant time frame increases are associated with the mean short departure time category. The mean short departure time for the Driver Inattention group increases from 2.12 seconds in Table 3-6 to 2.71 seconds in Table 3-7. The mean short time frame in the Relinquished Steering Control group increases from 1.38 seconds in Table 3-6 to 1.87 seconds in Table 3-7. The time frames shown in Table 3-7 will be substituted for the time frames shown for the Driver Inattention and Relinquished Steering Control groups in Table 3-5.

A second aspect of Tables 3-6 and 3-7 merits discussion. In both referenced tables, the values shown for the mean short time frames are relatively greater than similar values shown for mean short time frames in Tables 3-4 and 3-5. For example, the mean short time frame shown for departures from curved segments in the Driver Inattention group in Table 3-7 is 95.88 percent of the value shown for the mean long time frame computed for departures from these same segments. In Table 3-5, the comparable mean short departure time frame is 65.53 percent of the value shown for the mean long time frame Similar discrepancies are noted for departures from straight segments in this causal factor group where the mean short time frame shown in Table 3-7 is 148.89 percent of the value of the long time frame, whereas, the comparable value in Table 3-5 is only 56.86 percent of the value of the long time frame This pattern also extends to the Relinquished Steering Control group where in Table 3-7 the mean short departure time from straight roadway segments is 105.88 percent of the mean long departure time from these segments, whereas, the comparable value in Table 3-5 is only 69.19 percent of the value of the long time frame. Patterns of this type are also found between Tables 3-6 and 3-4. This circumstance is associated with shallow departure angles within the Driver Inattention and Relinquished Steering Control causal factor groups and is further exacerbated by application of the circular arc calculation algorithm. The algorithm tends to shift the point at which the subject vehicle begins moving from its pre-crash travel position further rearward as compared to the straight line projection technique (i.e., further reduces the departure angle). Even a few examples of this type within the short departure time category can obscure the relationship between long and short departure times.

The circular arc calculation algorithm cannot be accurately applied to the Evasive Maneuver, Lost Directional Control, Vehicle Failure, and Vehicle Speed causal factor groups since these groups do not demonstrate the same shallow uniform arc trajectory patterns exhibited by the Driver Inattention and Relinquished Steering Control groups. Therefore, time frames for those groups will continue to reflect the straight line projection technique and the time frames shown for the Driver Inattention and Relinquished Steering Control groups will be the result of application of the circular arc calculation algorithm. The final combinations of time frame estimates are provided in Tables 3-8 and 3-9. These final estimates remain conservative in nature with the estimates for the Evasive Maneuver, Lost Directional Control, Vehicle Failure, and Vehicle Speed groups being the most conservative.

Table 3-7
Departure Time to Roadway or Shoulder Edge
Using Circular Arc Algorithm

Causal Factor	Roadway Alignment	Departure Time Shoulder/Roadway Edge	
		Mean Long Departure Time	Mean Short Departure Time
Driver Inattention	Curve	2.91	2.79
	Straight	1.80	2.68
	All	2.36	2.71
Relinquished Steering Control	Curve	5.96	1.77
	Straight	1.87	1.98
	All	3.91	1.87
Evasive Maneuver	Curve	#N/A	#N/A
	Straight	#N/A	#N/A
	All	#N/A	#N/A
Lost Directional Control	Curve	#N/A	#N/A
	Straight	#N/A	#N/A
	All	#N/A	#N/A
Vehicle Failure	Curve	#N/A	#N/A
	Straight	#N/A	#N/A
	All	#N/A	#N/A
Vehicle Speed	Curve	#N/A	#N/A
	Straight	#N/A	#N/A
	All	#N/A	#N/A
	Total	3.39	2.20

Table 3-8
Departure Time to Roadway Edge
(Straight Line Projection and Circular Arc Derived Causal Factors)

Causal Factor	Roadway Alignment	Departure Time Roadway Edge	
		Average Long Departure Time	Average Short Departure Time
Driver Inattention	Curve	2.91	2.02
	Straight	1.80	2.15
	All	2.36	2.12
Relinquished Steering Control	Curve	5.96	1.26
	Straight	1.60	1.50
	All	3.78	1.38
Evasive Maneuver	Curve	#N/A	0.37
	Straight	1.28	0.54
	All	1.28	0.50
Lost Directional Control	Curve	1.77	#N/A
	Straight	1.26	1.05
	All	1.52	1.05
Vehicle Failure	Curve	#N/A	1.02
	Straight	1.84	0.57
	All	1.84	0.69
Vehicle Speed	Curve	1.56	0.75
	Straight	1.70	1.00
	All	1.63	0.81
	Total	**1.93**	**1.20**

Table 3-9
Departure Time to Shoulder/Roadway Edge
(Straight Line Projection and Circular Arc Derived Causal Factors)

Causal Factor	Roadway Alignment	Departure Time Shoulder/Roadway Edge: Average Long Departure Time	Average Short Departure Time
Driver Inattention	Curve	2.91	2.79
	Straight	1.80	2.68
	All	2.36	2.71
Relinquished Steering Control	Curve	5.96	1.77
	Straight	1.87	1.98
	All	3.91	1.87
Evasive Maneuver	Curve	#N/A	0.81
	Straight	1.33	1.06
	All	1.33	1.01
Lost Directional Control	Curve	2.12	#N/A
	Straight	1.54	1.45
	All	1.83	1.45
Vehicle Failure	Curve	#N/A	2.21
	Straight	1.84	0.82
	All	1.84	1.17
Vehicle Speed	Curve	1.73	1.12
	Straight	1.72	1.04
	All	1.73	1.10
	Total	**2.08**	**1.65**

3.4 Final Collision Taxonomy

The final collision taxonomy is comprised of the dynamic scenario groupings and characteristics of these groupings as indicated in Tables 3-l and 3-2, the qualitative intervention time frame assessments as indicated in Table 3-3, and quantitative time frame assessments as indicated in Tables 3-8 and 3-9. The most direct presentation method for this information is to incorporate the qualitative and quantitative time assessments into the summary situation trees developed in Task 1 and reviewed in Section 3.1 of this report. These summary trees are reproduced as Figures 3-4 through 3-9 on the following pages. Time related data are reported in the lower left branch of each tree. The top two lines in each departure time frame branch indicate the distribution of long and short departure times from curved and straight roadway segments within the referenced causal factor group. The bottom two lines provide *mean* value estimates of the length of these long and short departure time frames for the referenced causal factor group. The mean value times reported in these figures are computed to the edge of roadway and do not include the shoulder area. Situation trees which incorporate departure times to the edge of the shoulder are provided in Appendix E.

Since the pre-existing events/conditions and other characteristics of each situation tree are known and documented, an alternative short-hand method for presenting the taxonomy is to designate the causal factor and available intervention time frames for this factor. This short-hand notation method is illustrated in Table 3-10 for departure times computed to the edge of roadway and Table 3-l 1 for departure times computed to the edge of the roadway or adjacent shoulder when a stabilized shoulder is present. With this presentation format, the reference characteristics of each causal factor group as indicated in Figures 3-4 through 3-9 are assumed to be an identified quantity implied by the causal factor title.

As a general point, the project staff believes that the distribution of and the length of the time frames indicated by the final taxonomy provide sufficient opportunity to intervene in the dynamic scenarios and achieve crash avoidance/severity reduction. There are obvious differences between the causal factor groups in terms of available time and these differences are likely to affect both the approach to countermeasure development and the effectiveness of these approaches. This issue will be addressed in more depth in subsequent sections.

The information conveyed by the collision taxonomy will be used as the basis of the functional goal development sequence described in the next section. Specifically, functional goals will be developed to counteract the characteristics conveyed by the taxonomy and thus, achieve collision avoidance or crash severity reduction in those crashes which are not completely avoided.

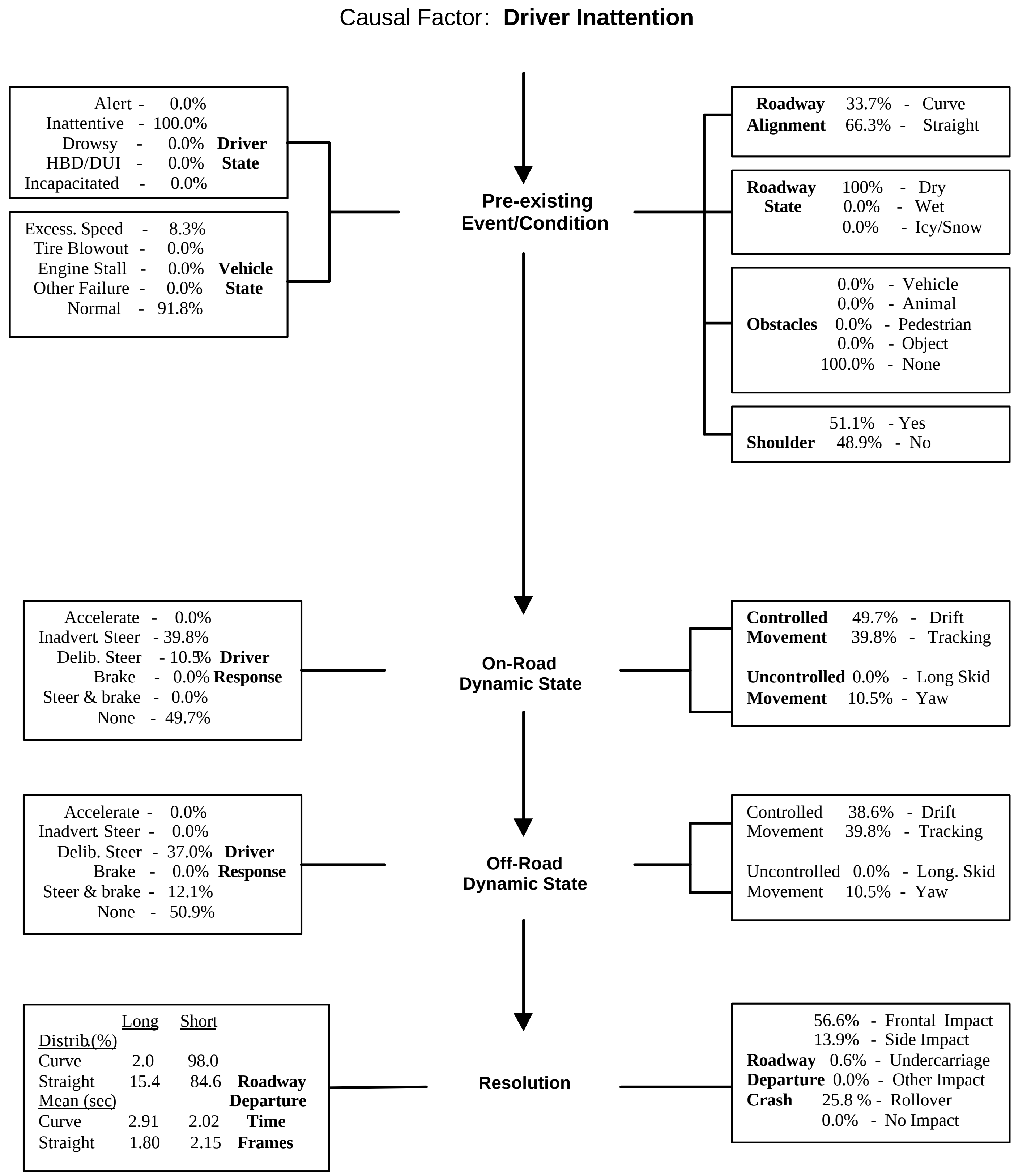


Figure 3-4 VEHICLE DYNAMIC SCENARIO ANALYSIS - DRIVER INATTENTION

Causal Factor: ***Driver Relinquished Steering Control***

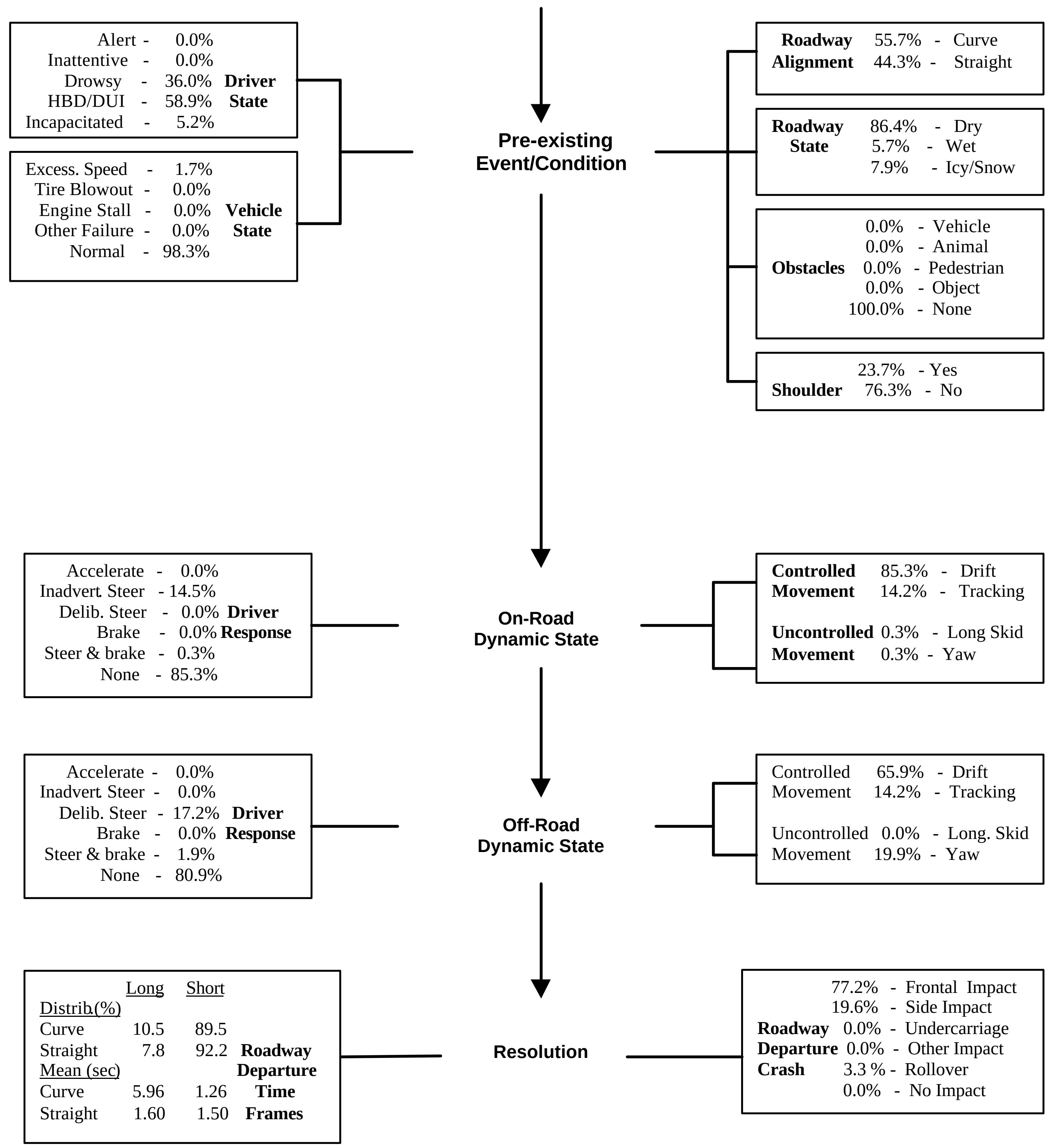


Figure 3-5 VEHICLE DYNAMIC SCENARIO ANALYSIS - DRIVER RELINQUISHED STEERING CONTROL

Causal Factor: ***Evasive Maneuver***

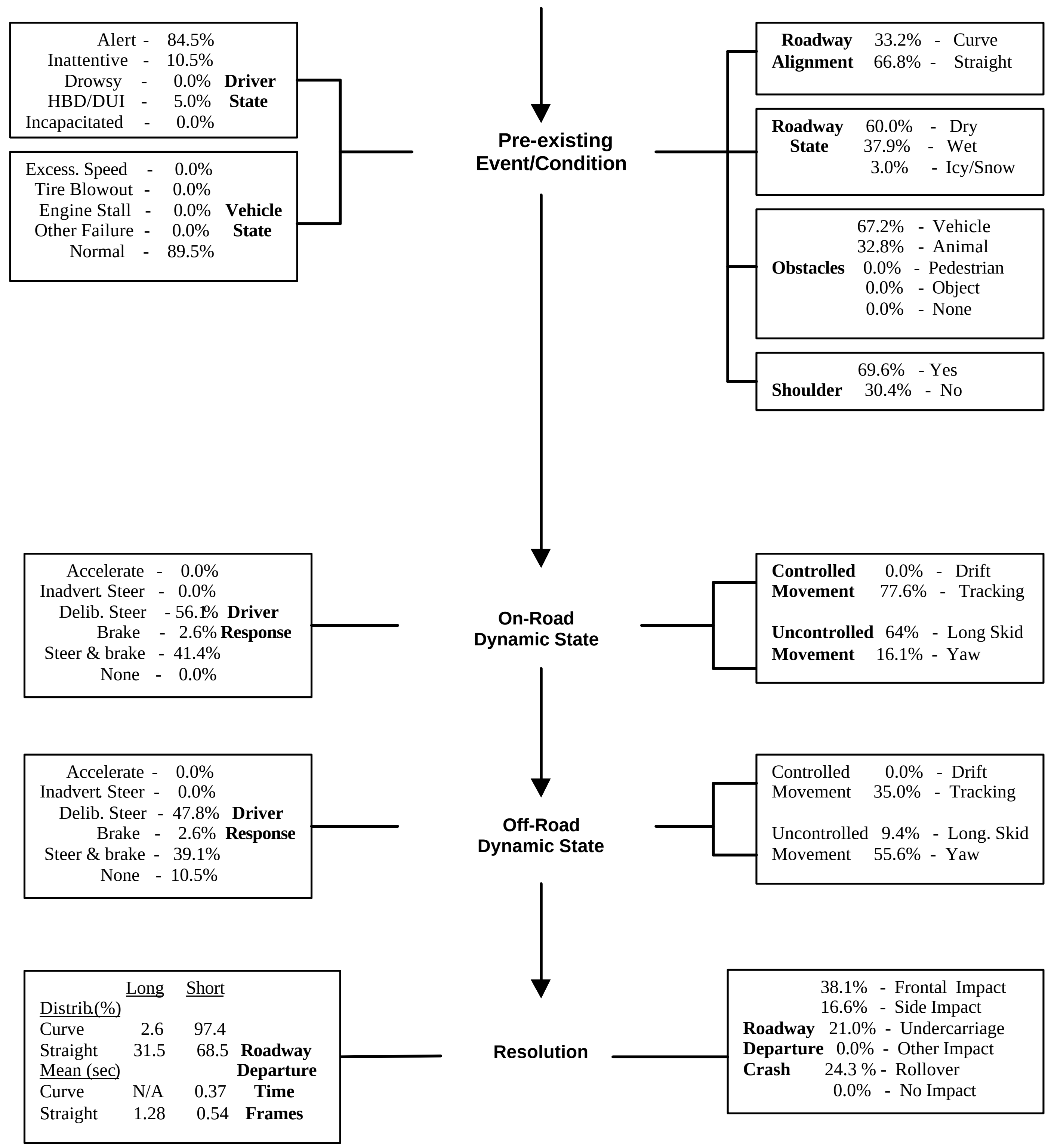


Figure 3-6 VEHICLE DYNAMIC SCENARIO ANALYSIS - EVASIVE MANEUVER

Causal Factor: ***Lost Directional Control***

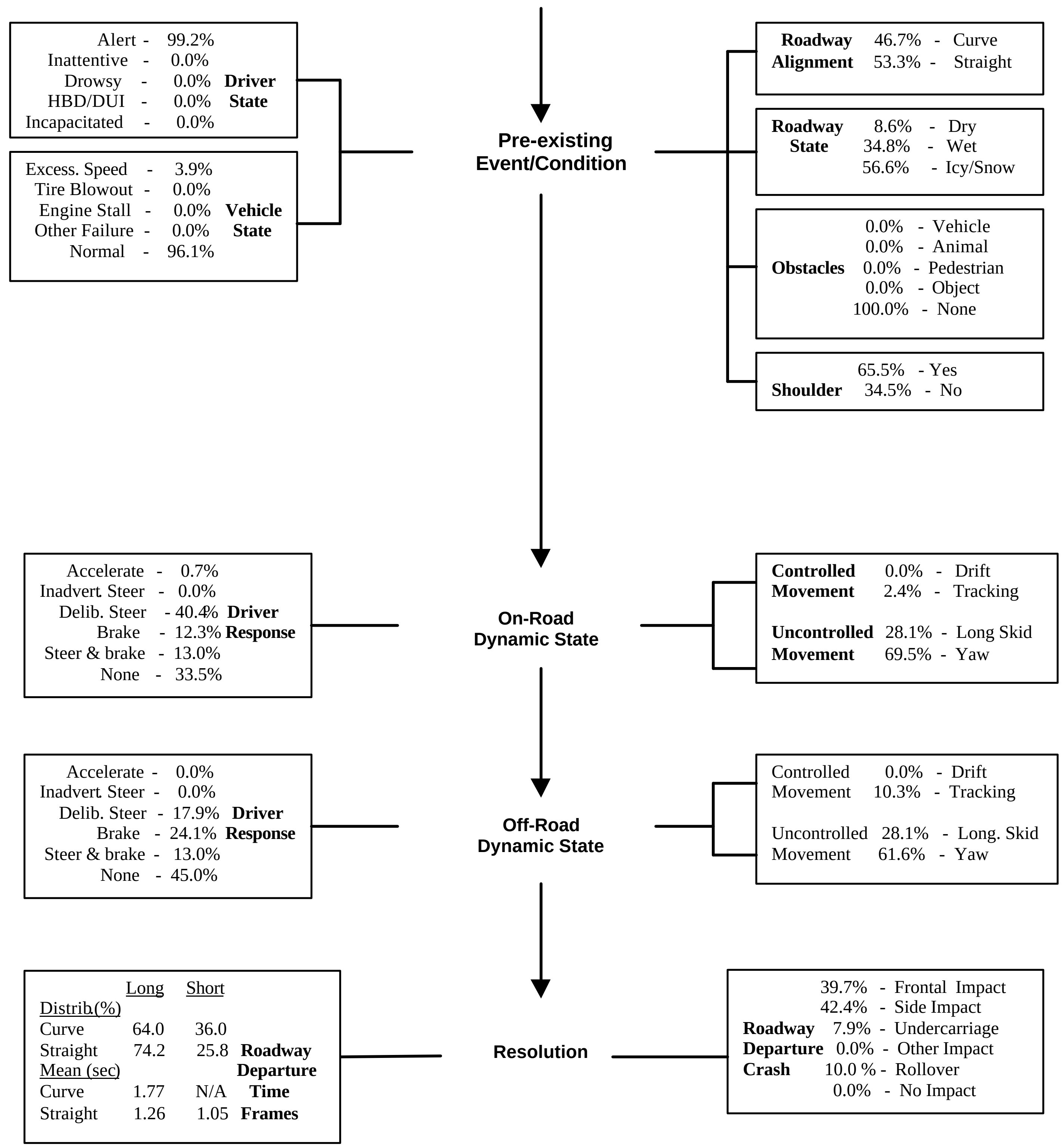


Figure 3-7 VEHICLE DYNAMIC SCENARIO ANALYSIS - LOST DIRECTIONAL CONTROL

Causal Factor: ***Vehicle Failure***

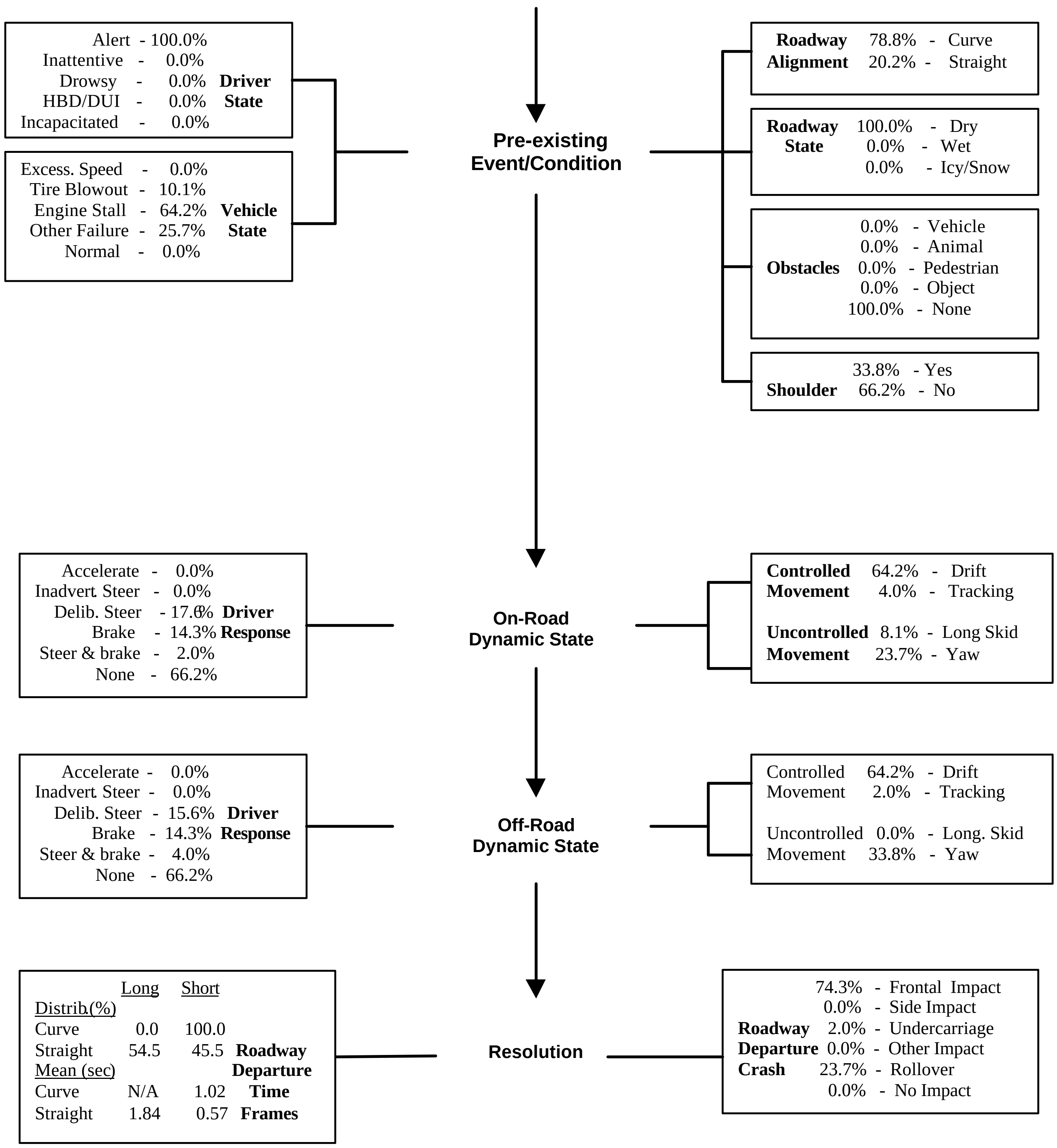


Figure 3-8 VEHICLE DYNAMIC SCENARIO ANALYSIS - VEHICLE FAILURE

Causal Factor: ***Vehicle Speed***

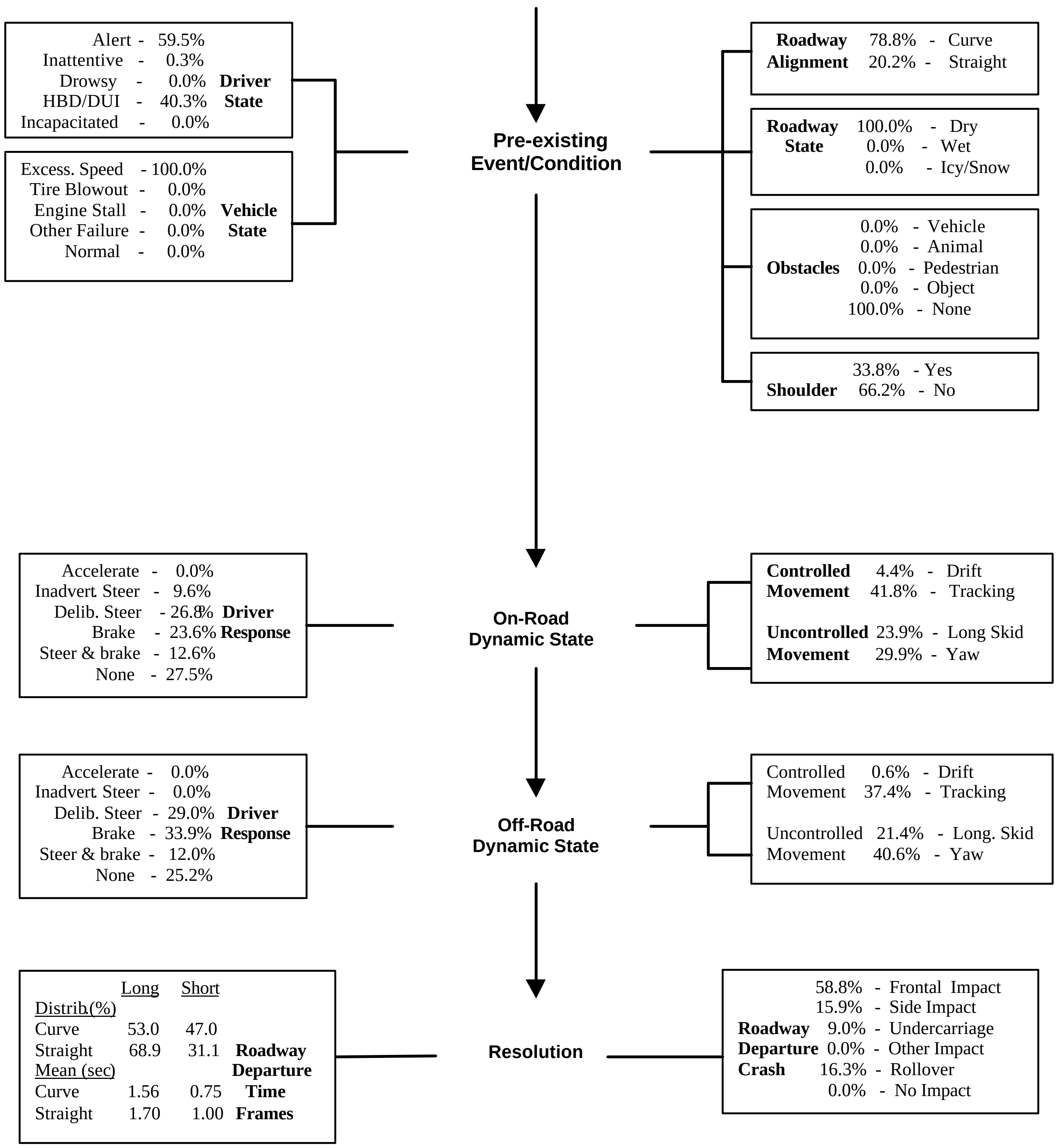


Figure 3-9 VEHICLE DYNAMIC SCENARIO ANALYSIS - VEHICLE SPEED

Table 3-10
Summary of Collision Taxonomy
Departure Times to Roadway Edge

Causal Factor and Roadway Alignment	Roadway Departure Times Frames			
	Long		Short	
	Distrib. (%)	Mean (sec)	Distrib. (%)	Mean (sec)
Driver Inattention				
Curve	2.0	2.91	98.0	2.02
Straight	15.4	1.80	84.6	2.15
Relinquished Steering Control				
Curve	10.5	5.96	89.5	1.26
Straight	7.8	1.60	92.2	1.50
Evasive Maneuver				0.37
Curve	2.6	N/A	97.4	0.54
Straight	31.5	1.28	68.5	
Lost Directional Control				
Curve	64.0	1.77	36.0	N/A
Straight	74.2	1.26	25.8	1.05
Vehicle Failure				
Curve	0.0	N/A	100.0	1.02
Straight	54.5	1.84	45.5	0.57
Vehicle Speed				
Curve	53.0	1.56	47.0	0.75
Straight	68.9	1.70	31.1	1.00

Table 3-l 1
Summary of Collision Taxonomy
Departure Times to Shoulder/Roadway Edge

Causal Factor and Roadway Alignment	Roadway Departure Times Frames			
	Long		Short	
	Distrib. (%)	Mean (Sec.)	Distrib. (%)	Mean (Sec.)
Driver Inattention				
Curve	2.0	2.91	98.0	2.79
Straight	15.4	1.80	84.6	2.68
Relinquished Steering Control				
Curve	10.5	5.96	89.5	1.77
Straight	7.8	1.87	92.2	1.98
Evasive Maneuver				
Curve	2.6	N/A	97.4	0.81
Straight	31.5	1.33	68.5	1.06
Lost Directional Control				
Curve	64.0	2.12	36.0	N/A
Straight	74.2	1.54	25.8	1.45
Vehicle Failure				
Curve	0.0	N/A	100.0	2.21
Straight	54.5	1.84	45.5	0.82
Vehicle Speed				
Curve	53.0	1.73	47.0	1.12
Straight	68.9	1.72	31.1	1.04

4.0 Development of Countermeasure Functional Goals

The taxonomy described in Section 3.0 illustrates major characteristics of the run-off-road crash problem. These characteristics, such as the crash causal factors, roadway environment, and driver status play important roles in the collision. Countermeasure functional goals address these and additional features of the dynamic crash scenario. This section will apply countermeasure functions to the causal factor groups identified in the collision taxonomy to develop set(s) of functions. These resulting groups of functions will be examined, and similar functions will be merged to create a set or sets of key functions that run-off-road countermeasures should include.

4.1 Sample of Run-Off-Road Crashes Derived From Collision Taxonomy

The taxonomy as described in Section 3.4 consists of six groupings based on the causal factors associated with the crashes. These groupings, and the relative proportion of the sample comprised by the groupings are illustrated in Table 4-1 below:

Table 4-1
Causal Factor Groups
and
Proportion of Total Sample

Causal Factor Group	Percentage of Sample (%)
Driver Inattention	12.7
Relinquished Steering Control	20.1
Evasive Maneuver	15.7
Lost Directional Control	16.0
Vehicle Failure	3.6
Vehicle Speed	32.0
Total	**100.0**

NOTE: Weighted Values

The listing provided in Table 4-l contains causal factor groups that will be deleted from the functional goal development sequence due to the out-of-scope nature of these crashes to the run-off-road problem. Specifically, two of the groupings included in the table are associated with factors not directly related to roadway departure. These two crash types are Evasive Maneuver and Vehicle Failure. The rationale for omitting these groups is developed in the material which follows.

Crashes in the Evasive Maneuver group are the result of drivers exercising positive vehicle control in an event that occurred prior to roadway departure. In this grouping, the event is avoidance of a vehicle/animal/object in the subject vehicle's travel lane. The roadway departure results from steering maneuvers to avoid this initial encounter. Crashes that result from a previous encounter are best addressed by a forward-looking obstacle detection system. This type of system is being developed as part of a separate NHTSA-funded Performance Specification program. This program, Rear-End Collision Avoidance Using IVHS Countermeasures, will develop a forward-looking obstacle detection system. In addition to this duplication of effort issue, there is also a question as to when it is appropriate to prevent the driver from departing the road. In cases where a vehicle is intruding into the subject vehicle's lane, a driver observing a usable shoulder, may elect to depart the roadway to prevent the collision. A countermeasure designed to prevent these types of roadway departures may impede a driver from performing these maneuvers. For these reasons, the Evasive Maneuver group is excluded from the functional goal development sequence,

The elimination of Vehicle Failure crashes from the development sequence is due to the out-of-scope nature of this problem. In these cases, the roadway departure is a result of a loss of vehicle control due to vehicle component failure. A comprehensive vehicle monitoring system would be required for the prevention of these crashes. Clearly, this is out of the scope of work for this program.

The final sample of crashes utilized for the development of countermeasure functional goals is illustrated in Table 4-2 below. Specifically, these cases and associated crash types will form the basis of the functional goal analysis intended to guide development of performance specifications for run-off-road collision avoidance countermeasures.

Table 4-2
Final Run-Off-Road
Collision Sample

Causal Factor Group	Percent Original Sample (%)	Number of Cases
Driver Inattention	12.7	27
Relinquished Steering Control	20.1	48
Lost Directional Control	16.0	26
Vehicle Speed	32.0	65
Total	**80.8**	**166**

NOTE: "Percent Original Sample" values are weighted percentages

4.2 General Functional Goal Requirements of Run-Off-Road Countermeasures

Development of countermeasure functional goals for run-off-road collisions utilizes results of the vehicle dynamic scenario analyses that were provided in the Task 1 Interim Report. These dynamic scenarios illustrate characteristics of crashes such as driver and vehicle states, roadway alignment and state, and driver responses to on-and off-road dynamic states. The scenarios are, therefore, an excellent resource for the development sequence. Prior to examining potential functional goals, it is beneficial to review the general requirements to be utilized by run-off-road countermeasures. These requirements are summarized in Figure 4-l. As is evident from the figure, there are three distinct attributes for functional goals. These attributes are segregated by *what the* functional goal should accomplish. It should be noted that more than one functional goal may be used to satisfy the general requirement.

The first guideline relates to countermeasure functions that acquire data on vehicle state. This function is utilized throughout the time when the vehicle is in service. An example of this function is monitoring of a suite of sensors to determine vehicle velocity and acceleration. The second guideline relates to functions that process data from the roadway. This function, again using sensors on-board the vehicle or in the infrastructure, acquires and processes data to determine the configuration of the roadway, the position of the vehicle relative to the roadway, and if the roadway conditions can support the vehicle's velocity. The third guideline is for those functions that issue warnings of an unsafe condition or situation to the driver. Such conditions may be an icy or slippery roadway surface or a sharp curve. These three categories of countermeasure functions were applied to the clinical sample developed previously in Task 1. Further details of the sequence through which the countermeasure functions were derived are discussed below.

4.3 Development of Run-Off-Road Countermeasure Functional Goals

The review of the causal factor groupings developed in Section 3.0 produced a listing of functional goals for a run-off-road countermeasure. A brief description of the procedure followed **is** provided below:

1. Each causal factor group was analyzed to determine those functional goals that would prevent, or lessen the severity of, the crash.

2. The sets of functional goals developed for the groups were merged with duplicate entries omitted.

3. A final set of functional goals that would serve all causal factor groups was compiled.

The final set of functional goals for the run-off-road countermeasure is shown in Table 4-3. Included in this table is a brief description of each goal. Additional detail as to the nature of each functional goal is provided in the material that follows Table 4-3.

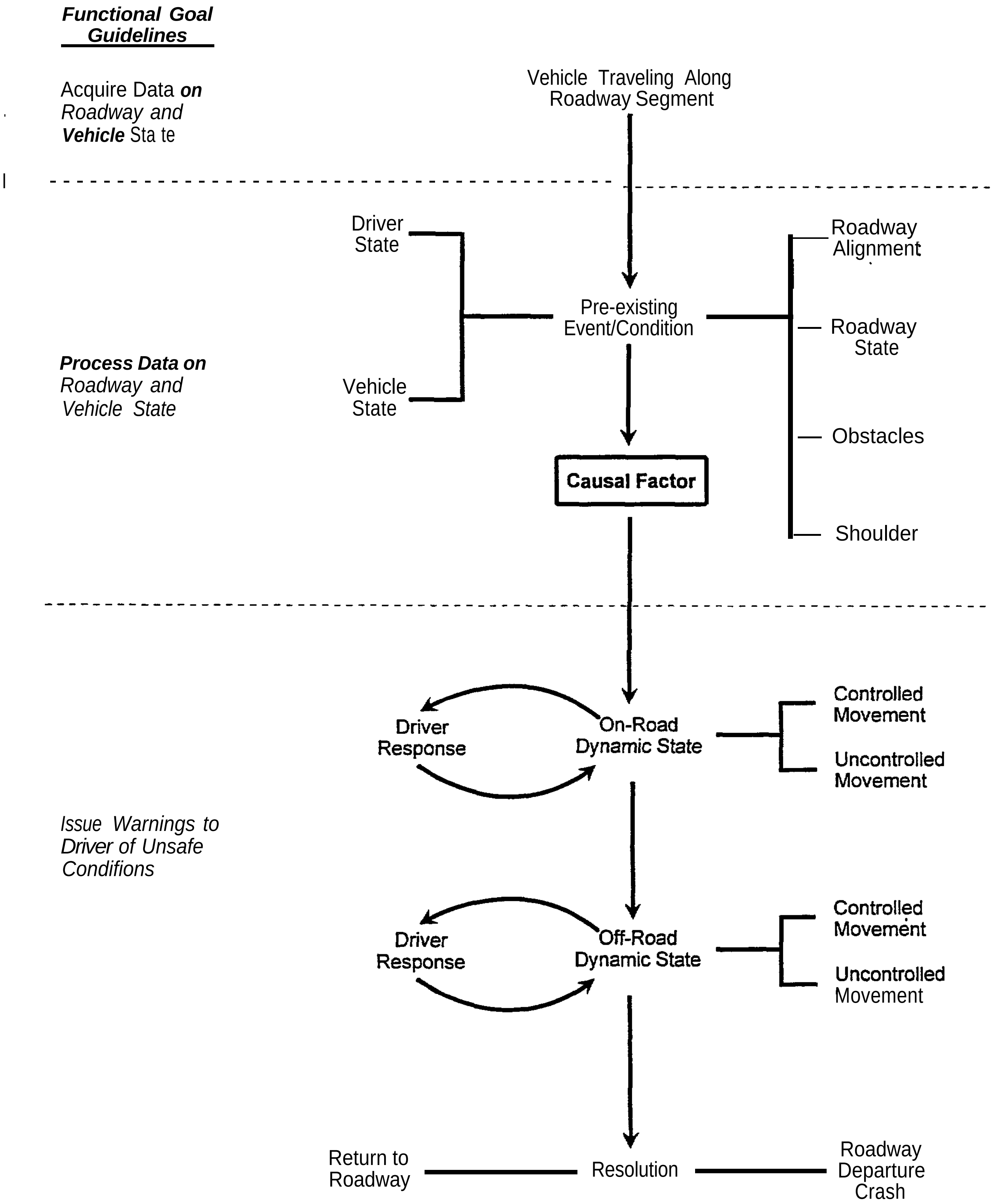


Figure 4-1 RUN-OFF-ROAD COLLISION AVOIDANCE COUNTERMEASURE GUIDELINES

Table 4-3
Functional Goals for a
Run-Off-Road Countermeasure

Goal Number	Functional Goal	Description
(1)	Monitor vehicle dynamic status	Monitor following vehicle parameters: a. Velocity b. Lateral acceleration c. Longitudinal acceleration d. Vehicle heading e. Radius of curvature
(2)	Determine geometric characteristics of upcoming roadway segment	Determine the following characteristics of the upcoming roadway segment: a. Number of lanes b. Lane width c. Roadway alignment (straight, curve right/left) d. Curvature of roadway segment e. Roadway superelevation f. Presence of exits or cross streets
(3)	Determine vehicle position/orientation relative to roadway	Determine vehicle position/orientation relative to roadway. Include characteristics listed below: a. Current travel lane b. Lateral position within lane c. Relative alignment of vehicle and roadway d. Distance from approaching curve
(4)	Determine driver intention	Determine driver intention to perform the following actions: a. Evasive maneuver b. Turning at cross street c. Pulling off to side of roadway (non-evasive maneuver)

Table 4-3
Functional Goals for a Run-Off-Road Countermeasure
(Cont.)

Goal Number	Functional Goal	Description
(5)	Detect degraded roadway condition	Detect the presence of roadway conditions such as water, snow, or ice that require special caution in vehicle operation.
(6)	Process data to determine acceptable speed for approaching roadway segment	Process information regarding approaching roadway segment alignment, roadway surface conditions, and vehicle dynamic state to determine the speed at which the vehicle can safely traverse segment.
(7)	Detect potential for roadway departure	Process following information to determine vehicle potential for roadway departure: a. Roadway alignment b. Number of lanes c. Width of lanes d. Vehicle position within lane e. Relative alignment of vehicle and roadway
(8)	Present alert of degraded roadway condition	Present alert to driver of degraded roadway conditions that require modification in mode of vehicle operation.
(9)	Present alert of approaching curve geometry	Draw driver's attention to an approaching curved roadway segment.
(10)	Present alert of excessive speed for approaching curve geometry	Data from functional goals dealing with approaching roadway geometry and determination of acceptable speed are presented to the driver in the form of an advisory indicating excessive speed.

Table 4-3
Functional Goals for a
Run-Off-Road Countermeasure
(Cont.)

Number	Functional Goal	Description
(11)	Determine driver state	Determine the state of the driver through observation of driver control inputs to the vehicle. This system would :learn" the manner in which the driver exercises vehicle control and observe changes in those behaviors.
(12)	Modulate driver control input	Identify excessive or insufficient driver input to steering based upon roadway configuration, vehicle position on roadway, velocity, and other factors. Reduce or amplify driver input as determined necessary.
(13)	Present alert of driver impairment	Present information to driver regarding reduced ability to control vehicle within acceptable performance criteria.
(14)	Present warning of excessive speed	Present a warning to the driver that the vehicle is traveling too fast for the roadway geometry or ambient roadway conditions.
(15)	Present warning of excessive vehicle lateral movement	This warning would indicate that the driver is controlling the vehicle in a manner that may lead to a roadway departure.
(16)	Momentary control intervention	Provide vehicle control inputs to primary controls to return the vehicle to the roadway travel lane. This input would be limited in duration.
(17)	Safe vehicle attitude	Assume authority over vehicle control functions and guide vehicle to safe position on side of road.

The functional goals listed in Table 4-3 are at this point technology independent. That is, they are merely data, actions, or warnings that a countermeasure could provide the driver to avoid the collision. In the next task of this program, countermeasure(s) utilizing these functional goals will be conceptualized. A brief explanation of each of the functional goals is presented below.

4.3.1 Monitor Vehicle Dynamic Status

The countermeasure would have the ability to monitor the dynamic status of the vehicle. The dynamic status is defined as the motion and directional vector that the vehicle is experiencing at any given time. Equipment on-board the vehicle will determine vehicle speed, and accelerations along vehicle lateral and longitudinal axes. Additional equipment will monitor vehicle heading (direction that the vehicle is traveling) and the radius of curvature of the vehicle path. These functions will monitor vehicle dynamic status data during vehicle operation. This feature has potential for use in countermeasures applicable to crash types other than roadway departure crashes.

4.3.2 Determine Geometric Characteristics of Upcoming Roadway Segment

Equipment on-board the vehicle or in the infrastructure would determine the following characteristics of the approaching roadway segment:

- Number of roadway lanes
- Lane width
- Roadway alignment (straight versus right/left curve)
- Curvature of roadway segment
- Roadway superelevation
- Presence of exits or cross streets

This information can be used by computers on-board the vehicle to assemble a situation map of the roadway segment that the vehicle is about to traverse. This function is identified as “ roadway preview” and this function establishes the conditions through which the vehicle must travel. In conjunction with the first function, monitor vehicle dynamic status, computers on-board the vehicle would determine if the vehicle is traveling at a speed appropriate for the approaching roadway segment. The function of determining the presence of exits or cross streets would allow the countermeasure to infer if a potential roadway departure by the driver is a change of trafficway to an exit or cross street rather than an actual departure. Many of the informational items listed above may be included as part of an on-board map database.

4.3.3 Determine Vehicle Position/Orientation Relative to Roadway

The countermeasure would determine the position of the vehicle within the context of the roadway on which it is traveling. The position of the vehicle would be determined with respect to the distance to the roadway segment where roadway departure may occur, such as an approaching curve. Another feature is the determination of the alignment of the vehicle’s travel path in relation to the current roadway segment. This may be used by the countermeasure to monitor driver control behavior and to determine when a lane deviation is indicative of an imminent departure rather than a normal vehicle drift within the lane.

Other features that the countermeasure would have are the ability to determine the travel lane that the vehicle is occupying and the vehicle's lateral position within the lane. This information is vital to accurately determining imminent roadway/lane departure.

4.3.4 Determine Driver Intention

The countermeasure would differentiate between a driver intention to perform a roadway departure and the following maneuvers:

- Evasive maneuver to avoid a vehicle, object, or animal in the roadway
- Turning at a cross street
- Pulling off to side of roadway (non-evasive maneuver)

The countermeasure would monitor vehicle dynamic state and driver control actions to determine intention. For example, the countermeasure may detect the vehicle proceeding to the right edge of the roadway accompanied by a deceleration. On reviewing the digital map data on-board, the countermeasure determines that a cross street is ahead at a distance of 100 feet. The countermeasure monitors the vehicles deceleration and distance to the cross street and recognizes that the driver is slowing to perform a right turn at the cross street. Upon determining that the driver is exercising control of the vehicle, and that the vehicle is operating within a nominal range, no warning is issued.

4.3.5 Detect Demaded Roadway Condition

The countermeasure would determine if the roadway surface is degraded by environmental factors such as water, snow, or ice. This function may be accomplished by equipment on-board the vehicle or sensors in the roadway.

4.3.6 Process Data to Determine Acceptable Speed for Approaching Roadway Segment

The countermeasure would acquire details of the configuration of the approaching roadway segment, the condition of the roadway, and the dynamic state of the vehicle and determine an acceptable travel velocity for this segment. As the vehicle approaches the segment, the countermeasure would monitor any change in dynamic state to determine if the vehicle is responding to the roadway configuration and conditions. If the driver does not respond to the configuration and conditions, an alert would be issued.

.

4.3.7 Detect Potential for Roadway Departure

The countermeasure would process the following data to determine the potential for the vehicle to depart the roadway and to determine the immediacy of the impending departure.

- Roadway configuration
- Vehicle position on roadway
- Vehicle path
- Vehicle dynamic state
- Driver intention

A warning would be issued to the driver if the current vehicle path would result in a departure from the roadway. This warning would be tied to the immediacy of the departure.

4.3.8 Present Alert of Degraded Roadway Condition

The countermeasure would alert the driver of the existence of a degraded roadway condition. The countermeasure may indicate the source of the degradation or present an advisory of an appropriate speed to traverse the segment.

4.3.9 Present Alert of Approaching Curve Geometry

The countermeasure would present information to the driver regarding the geometry of the approaching roadway segment. Primarily, this function would be exercised when the approaching roadway segment includes a curve. The countermeasure would present information either through auditory, or visual modes, concerning the direction of the curve and the radius of the curve. This information would be presented in a timely manner that would allow the driver to adjust the vehicle travel speed for the segment.

4.3.10 Present Alert of Excessive Speed for Approaching Curve Geometry

In coordination with the curve geometry functional goal, this goal would compare the outputs of the curve geometry and vehicle dynamic status goals and then establish appropriate speed functional goals to alert the driver of an excessive speed condition. This alert would be provided in multiple modalities with sufficient time to allow the driver to react and adjust the speed of the vehicle.

4.3.11 Determine Driver State

The countermeasure would monitor the behavior that the driver exhibits in controlling the vehicle. These behaviors are manifested in the way in which the driver normally initiates the steering, braking, and throttle inputs, or in the resulting vehicle behavior. For example, the system may monitor the driver's behavior by determining the current position of the vehicle in the travel lane and comparing this position to the driver's normal or preferred position. Deviations from the normal pattern of behavior exhibited by the driver can indicate an altered driver state.

4.3.12 Modulate Driver Control Input

The countermeasure would determine appropriate ranges of driver control inputs for functions such as steering, braking, and throttle. This function, when applied to the steering, can assist the driver by modulating the steering that may be initiated to regain control after an evasive maneuver. In the aerospace industry, this is termed "pilot induced oscillation", where a pilot's input to the control stick leads to a series of increasing magnitude oscillations. In this application, the countermeasure would utilize other available data such as the position of the vehicle on the roadway, configuration of the approaching roadway segment, and driver intention to determine if the control input is appropriate. This input may be to the steering wheel, brake pedal, or accelerator pedal. The countermeasure would determine if the input is within a range of acceptable inputs and either modulate the input to damp unwanted actions or amplify the input to prevent the crash. An example of this modulation is the driver initiating a large steering input while the vehicle is traveling at 65 mph. The countermeasure, sensing the input, would determine the consequences of this input at the given travel velocity. If the countermeasure determines that the input is excessive, it would limit the magnitude of the input or increase the time duration over which the input is produced.

4.3.13 Present Alert of Driver Impairment

The countermeasure would determine if a driver is impaired and present an alert of the degraded condition. This functional goal has wide ranging applications and should detect degradation of driver control abilities caused by driver fatigue, alcohol, and other reasons. The countermeasure would monitor the manner in which the vehicle is controlled by the driver and determine when these characteristics are unsafe. This countermeasure would present an alert in multiple modalities such as audio and/or visual with the intent of informing the driver of degrading/deteriorating control abilities. If the driver chooses to ignore this alert, the countermeasure may safe the vehicle. The functions of a system described above should be examined thoroughly with criteria for a trade-off between presenting an alert and sating of the vehicle carefully considered.

4.3.14 Present Warning: of Excessive Speed

The countermeasure would process data on vehicle dynamic state, roadway configuration, and issue a waming to the driver of excessive speed for the prevailing situation. This warning would be presented after an alert has been issued. A warning is issued when vehicle speed must be adjusted in a very short time frame. This time frame is one characteristic that differentiates a warning from an alert. An alert is issued when a particular condition (such as vehicle speed) or roadway configuration (such as a curve), that may require the driver to modify current control levels, is detected. A warning would be issued after an alert in the absence of an appropriate driver response. The modality of the warning is a secondary means of differentiating an alert from a warning. A warning may use visual and auditory means to transmit the message to the driver, but it may also use haptic means to convey the immediacy of the need to respond. An example of the application of a haptic warning would be to increase the pressure required to depress the accelerator pedal.

4.3.15 Present Warning of Excessive Vehicle Lateral Movement

This functional goal would warn the driver of an impending roadway departure. The system would monitor vehicle position/orientation, and present the warning when the system detects that departure is imminent. The warning may be presented to the driver in the form of a visual or auditory warning, similar to the excessive speed warning. However, it may be necessary for the countermeasure to assume momentary control of the steering to return the vehicle to the roadway. This feature is described in the functional goal that follows.

4.3.16 Momentary Control Intervention

If no driver response is received to other forms of warnings (e.g., auditory, visual, or haptic), the countermeasure would provide vehicle control inputs to primary controls to return the vehicle to the roadway travel lane. The duration of input would be limited with the intention of indicating a recommended course of action to the driver. For example, the countermeasure could provide directional corrections to the steering wheel to indicate that the vehicle is too close to the shoulder. The goal of this countermeasure function is to aid the driver's decision-making process in performing actions that will provide the safe return of the vehicle to the roadway.

4.3.17 Safe Vehicle Attitude

The countermeasure would recover a "safe" vehicle attitude by active control of vehicle control functions. If no response is received with respect to initial warning forms, the countermeasure would assume steering, braking, and throttle control. The countermeasure would control vehicle dynamic state and attitude until the driver exercises control over vehicle functions, or if the driver does not exercise control, the countermeasure maintains vehicle control to regain a "safe" attitude. Once a safe attitude is attained, the countermeasure would slow the vehicle and guide it to the side of the road. Again, this function would only be exercised if there is no driver response to warnings.

4.4 Results of Application of Functional Goals to NASS Cases

This section documents the application of the functional goals listed in Section 4.3 to the sample of NASS run-off-road collisions used previously for clinical analyses. The cases were reviewed as causal factor groups to determine the commonality of functional goal elements. Within these scenarios the sets of countermeasure functional goals were very homogeneous. Results of the determination of functional goals for each causal factor group are described below. Typical examples of the application of the functional goals to collisions within each group are detailed in this section.

4.4.1 Distribution of Final Run-Off-Road Sample

The deletion of the causal factor categories detailed in Section 4.1 reduced the clinical sample to 166 cases. The causal factor groups in the remaining case sample were distributed as illustrated in Table 4-4 below:

Table 4-4
Distribution of Final Clinical Sample

Causal Factor Group	Number of Cases	Percent of Total Sample
Driver Inattention	27	16.3
Relinquished Steering Control	48	28.9
Lost Directional Control	26	15.7
Vehicle Speed	65	39.1
Total	166	100.0

* These causal factor groups are examined individually in the sections that follow.

4.4.2 Driver Inattention Causal Factor Group

The Driver Inattention causal factor group accounts for 16.3 percent of the clinical sample examined. This group consists of those cases where the driver of the vehicle is not attentive to the driving task and leaves the roadway as a result of this inattention. A listing of the characteristics typical of the Driver Inattention group is provided in Figure 4-2. As evident in Figure 4-2, the Driver Inattention causal factor occurs primarily on straight roadway segments (65.7 percent) under dry roadway conditions. The vehicle movement toward roadway departure is classified as drifting or tracking in nearly 90 percent of the cases. Drifting is differentiated from tracking by the magnitude of the departure angle. Drifting is a low angle departure from the roadway, while tracking **is** characterized by a larger departure angle. The driver's response to the controlled movement (drift or tracking) is an approximate even split between a steering input (50.3 percent) and no response (49.7 percent).

A countermeasure to prevent the Driver Inattention causal factor group must be able to determine the dynamic state of the vehicle as it is traveling along the road. In addition, the countermeasure should determine the configuration of the approaching roadway segment. These two critical data elements are processed to determine if the driver is controlling the vehicle in a manner that will maintain a path on the roadway as opposed to resulting in a roadway departure. The use of countermeasure functional goals to prevent a crash caused by Driver Inattention is illustrated below. The dynamic scenario from a NASS CDS case acquired in Task 1 of this program is modified to show the use of the functional goals.

Causal Factor: ***Driver Inattention***

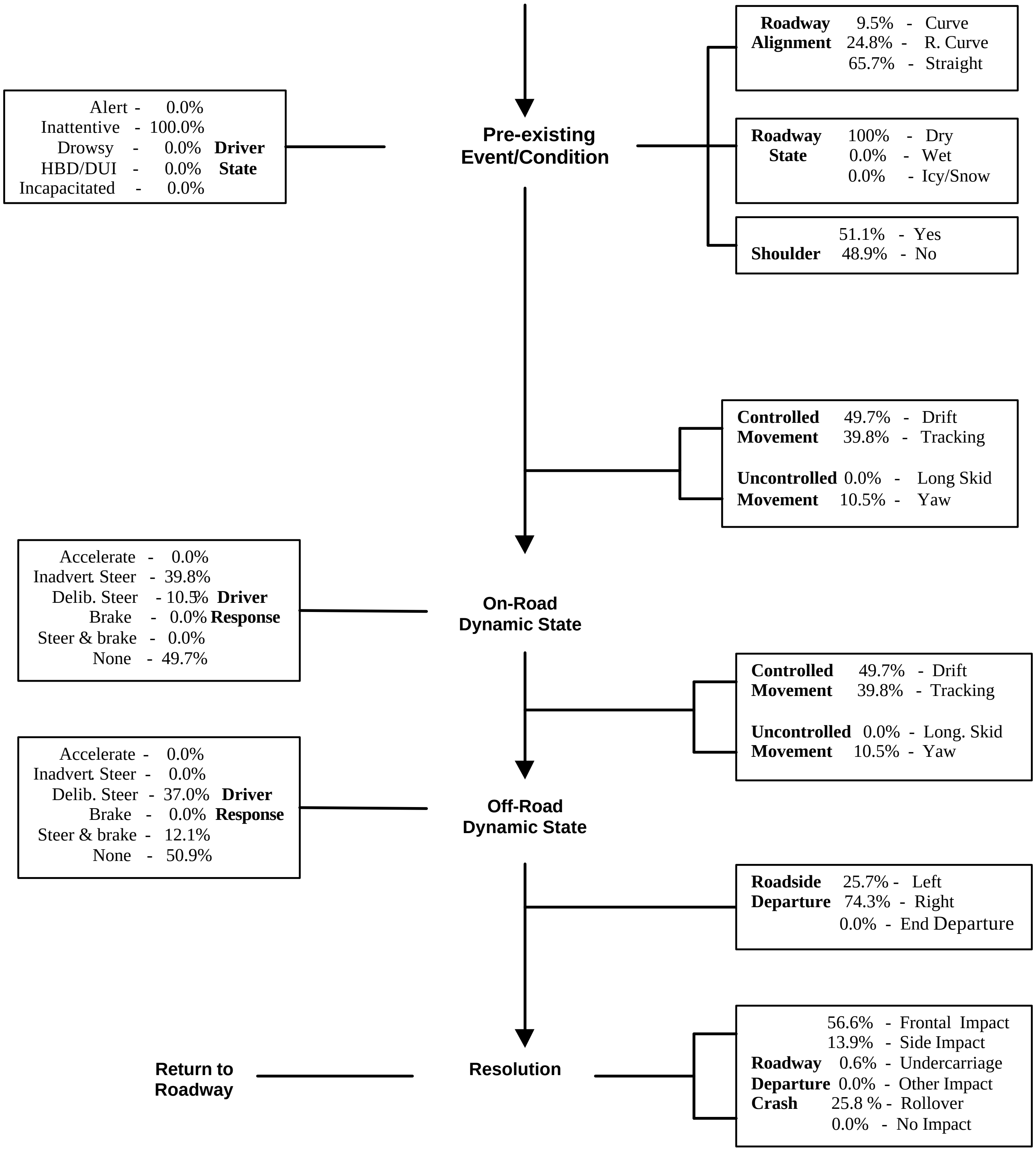


Figure 4-2 VEHICLE DYNAMIC SCENARIO ANALYSIS - DRIVER INATTENTION

4.4.2.1 ***Driver Inattention Causal Factor Group - Case No. 75-017***

This accident occurred on a rural, two lane undivided roadway at 4:20 PM. The driver of the vehicle was a 20 year-old male. The weather was clear, with some clouds, and the roadway surface condition was dry. The driver was traveling along a straight roadway segment, approaching a left curve. The driver diverted his attention out the right side of the vehicle to the surrounding countryside. The vehicle drifted onto the right shoulder prior to the driver taking any corrective action. The driver initiated a steering correction in an attempt to return to the roadway. The shoulder surface (gravel) could not support the maneuver and the vehicle transitioned into a yaw. The vehicle rotated counterclockwise and impacted a dirt and snow mound with its' right side, rolling over. A summary fact sheet for this case is provided in Figure 4-3. The scene diagram illustrating the roadway alignment, configuration of the roadway shoulder, and the trajectory of the vehicle as it left the roadway is presented in Figure 4-4. It is important to note in this case that the vehicle traveled along a shallow path, for a period of time toward the right shoulder, and in fact traveled to the shoulder prior to the driver becoming aware of this situation. This period, where the driver is on a path that ***could*** lead to a roadway departure, is the interval in which the countermeasure must operate to prevent the departure.

A run-off-road countermeasure has a number of opportunities to prevent this roadway departure. A convenient manner in which to illustrate this is to apply the countermeasure functional goals to the dynamic scenario diagram for this case. These diagrams illustrate pre-existing conditions/events, causal factor, on and off-road dynamic states, and the resolution of the sequence. The vehicle dynamic scenario for this case is shown in Figure 4-5. Also illustrated in Figure 4-5 are the countermeasure functional goals that would be applied to prevent ***this*** crash. A discussion of the application of each of the functional goals is presented below:

- Monitor Vehicle Dynamic Status

The equipment to monitor vehicle dynamic status would be active during the time the vehicle is operational. This equipment, which would likely be used by other collision avoidance systems, would monitor key parameters of what the vehicle is doing at any given time. Some of the parameters that the equipment would monitor are vehicle speed, heading, and the state of acceleration along the vehicle's longitudinal and lateral axes. The information provided by this suite of equipment provides part of the basic information that the on-board CPU requires to determine the potential for roadway departure.

- Determine Vehicle Position/Orientation Relative to Roadway

This functional goal would establish where the vehicle is in relation to the travel lane and the relative orientations of the vehicle's path and the roadway. On-board equipment would detect the movement of the vehicle toward the roadway shoulder. In this collision, the movement was a drift toward the shoulder. The countermeasure would measure this drift and warn the driver if the drift could result in a departure from the travel lane. In the implementation of this functional goal, it must be realized that drivers do not control vehicles

PSU-Case No.
75-017

CAUSAL FACTOR: *Driver Inattention*
ROADSIDE DEPARTURE: *Right*

General Accident Information

Date:	I-I-93	Weather:	Clear
Time	*1620*	*Surface Condition:*	Dry
Accident Type:	Control/Traction Loss	*Lighting:*	Daylight
Accident Severity:	*3 (A)*	Land *Use:*	Rural

Driver/Occupant Information

Driver Age:	*20*
Driver Sex:	*Male*
Impairment:	None
Familiarity *with Road:*	*Yes*
No. of *Occupants:*	*3*

Vehicle Information

Year:	*1980*
Vehicle Make:	Subaru
Vehicle Model:	DL/FE/G/GF GLF/STD
ASS:	*NO*
Defects:	NO

Roadway Information

Trafficway Type (Median):	*Not* divided	*Alignment*	Curve Left
		Slope:	Level
No. of Lanes:	*2*	*Speed Limit:*	*64 km/h*

Cluster Variables

GV14:	01 No avoidance actions
GV64:	13 Negotiating a curve
GV65:	06 This vehicle loss of control to traveling too fast for conditions
GV66:	0 No avoidance maneuver
GV67:	0 No avoidance maneuver

Calspan Corporation
Carnegie Mellon University

Run-Off-Road Collision Avoidance
Case Summary

Figure 43 RUN-OFF-ROAD COLLISION CASE SUMMARY
EXAMPLE OF DRIVER INATTENTION
Case No. 75-017

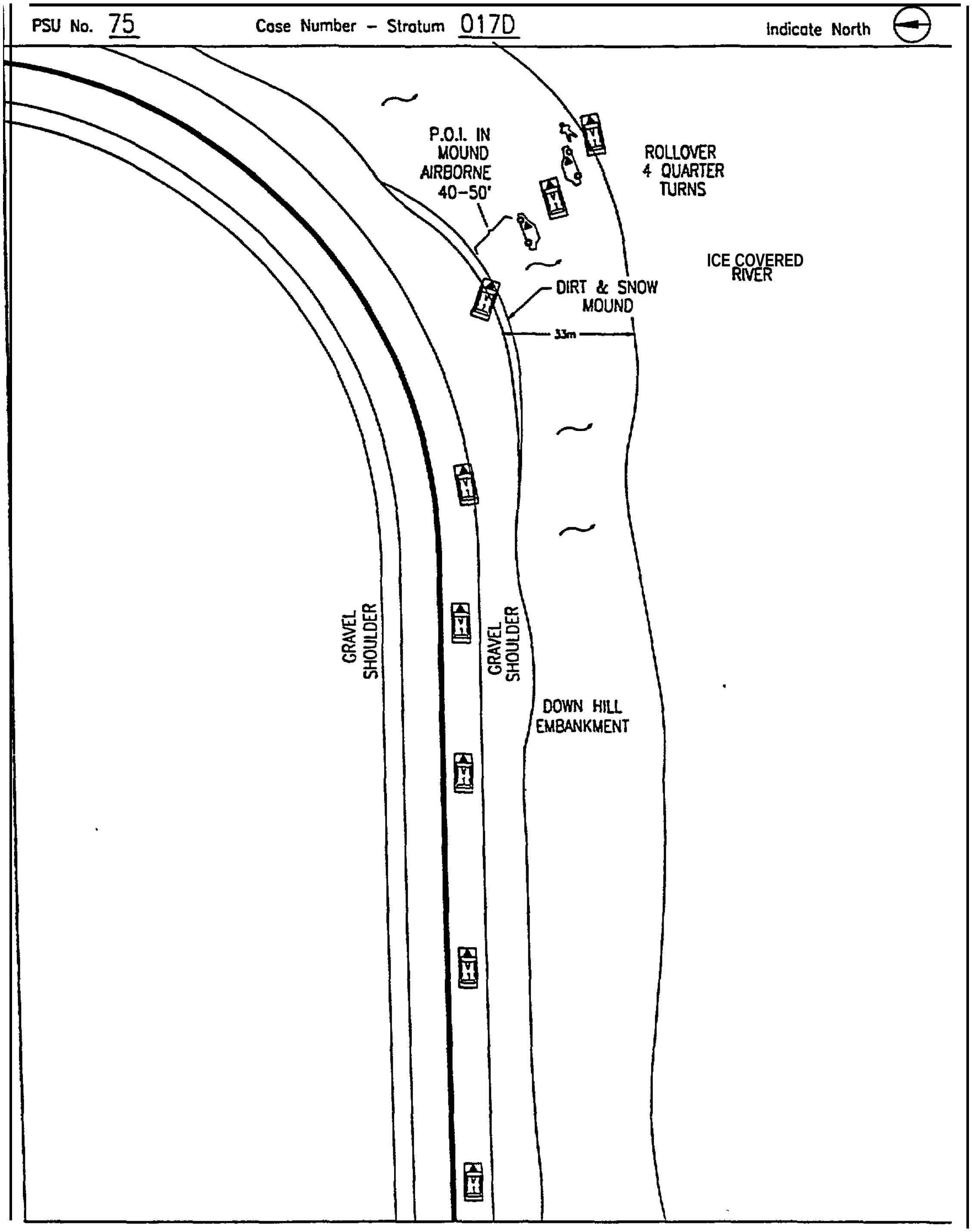
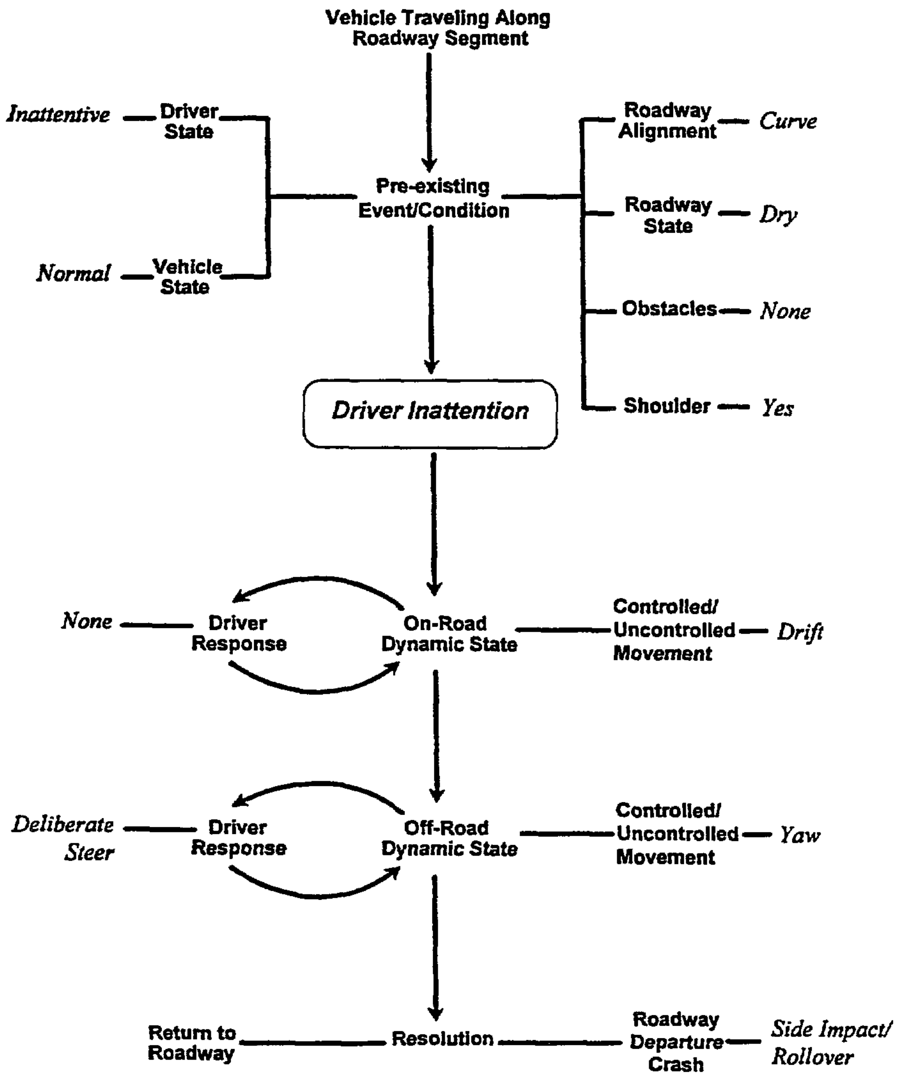


Figure 44 RUN-OFF-ROAD COLLISION DIAGRAM
EXAMPLE OF DRIVER INATTENTION
Case No. 75-017

Vehicle Dynamic Scenario
Causal Factor Grouping - Driver Inattention

Example PSU-Case No. 75-017



Functional Goals

- (1) Monitor vehicle dynamic status
- (3) Determine vehicle position/ orientation relative to roadway
- (2) Determine geometric characteristics of upcoming roadway segment
- (9) Present alert of approaching curve geometry
- (6) Process data to determine acceptable speed for approaching roadway segment
- (7) Detect potential for roadway departure
- (4) Determine driver intention
- (11) Determine driver state
- (15) Present warning of excessive vehicle lateral movement
- (16) Momentary control intervention
- (12) Modulate driver control input

Figure 4-5 RUN-OFF-ROAD COLLISION SEQUENCE WITH APPLIED FUNCTIONAL GOALS EXAMPLE OF DRIVER INATTENTION

with precision. That is, they do not track a path down the center of the travel lane. A driver will drift back and forth across the lane with the degree of drift being characteristic of individual drivers. The countermeasure must be able to differentiate this characteristic drift from a potential roadway departure. A system that could "learn" the habits of the driver would be advantageous in differentiating these types of behavior. The monitoring of the relative position of the vehicle within the lane could act to "arm" a driver warning or corrective action. For example, if the countermeasure has determined through observation of driver habits that the driver will generally drift within two feet of the lane boundaries, then a warning may be issued to the driver when this boundary is violated.

In this roadway departure crash , the countermeasure would have detected the drift of the vehicle. The countermeasure would determine that the vehicle's drift to the right would take it out of the travel lane. Other data that defines roadway characteristics would be stored on-board. These data would indicate the absence of a lane for the vehicle to enter. With this information, a warning could be issued to the driver. The substance of this warning will be discussed in a later functional goal.

- Determine Geometric Characteristics of Upcoming Roadway Segment

In order to determine the roadway configuration into which the vehicle is proceeding, the geometric characteristics of the roadway must be acquired. The characteristics that would be utilized in this case are described below:

a. Number of lanes - This characteristic would set the maximum lateral movement of the vehicle path acceptable to prevent roadway departure.

b. Lane width - This is complementary information used to determine the extent of the vehicle's lateral path.

c. Roadway alignment - Determine if the approaching roadway segment is straight or curved. In addition, provide information regarding the direction of curvature (left or right).

d. Curvature of roadway segment - This data would aid in the determination of an acceptable speed for the vehicle to safely traverse the approaching roadway segment.

e. Roadway superelevation - Along with roadway alignment this information would be used to determine an acceptable travel speed for a given roadway segment.

- Present Alert of Approaching Curve Geometry

The application of this functional goal could have been sufficient to prevent this crash. The presentation of an alert to the driver of an approaching curve could have led to the cessation of the driver's inattentive state. The alert would be presented at a sufficient distance from the curve that the driver could adjust vehicle speed in a safe manner.

- Process Data to Determine Acceptable Speed for Approaching Roadway Segment

This functional goal provides a preview of the roadway segment that the vehicle is approaching, and calculates an acceptable speed at which the vehicle may be operated. Data stored in the on-board digital map is compared with current vehicle position provided by a system such as DGPS (Differential Global Positioning System) to determine the configuration of the approaching roadway. Other information items that would be used in this functional goal are:

a. Current vehicle speed
b. Longitudinal acceleration (is the vehicle slowing or traveling at constant velocity)
c. Characteristics of upcoming roadway segment (e.g., surface condition, curvature, etc.)

- Detect Potential for Roadway Departure

This functional goal would process data from the various sensor suites and detect the potential for roadway departure. This calculation would primarily use data regarding vehicle position, roadway configuration, and vehicle dynamic status (including path) to ascertain if it is likely that the vehicle will depart the roadway if corrective action is not taken. If this determination is made, a phased warning is presented to the driver.

- Determine Driver Intention

The countermeasure would process data regarding vehicle control inputs by the driver, vehicle position/orientation on the road, and the potential for roadway departure to determine the driver's intention. In this case, the countermeasure would have to distinguish between an undesired drift of the vehicle off the roadway and the driver pulling off the roadway in a controlled manner. In cases of the driver pulling off the roadway, a countermeasure may present an alert to the driver and if an appropriate response to the alert is received, the driver would be allowed to complete the roadway departure. This function is closely linked to the determination of driver state. If the countermeasure can determine that the driver is exercising control of the vehicle and that conditions are adequate for the vehicle to depart the roadway (a usable shoulder exists), it can determine that the driver is consciously taking the vehicle off the roadway. This proposition should be examined closely since it could be a ***major source*** of false alarms.

- Determine Driver State

Once the countermeasure has determined that prevailing conditions do not warrant a departure from the roadway, the system would check on the status of the driver by determining the manner in which the driver has been exercising vehicle control. The system would also determine if the driver has been manifesting poor control behavior for a period of time prior to the current alert. If the driver has not exhibited poor control behavior, the system could infer driver inattention. If, however, the system determines that poor ***control*** behavior was exhibited prior to this warning, other forms of impairment may be inferred by the countermeasure.

- Present Warning of Excessive Vehicle Lateral Movement

If the countermeasure determines that the driver is not exercising adequate lateral control of the vehicle, a warning would be issued. This warning may have a number of potential levels. The first level would be a passive warning that incorporates either visual, audio, or both components to warn the driver of the threat of roadway departure. In Driver Inattention cases, drivers are not focusing on the driving task. This first level of warning may be sufficient to prevent these crashes. If this warning is insufficient, a haptic warning, such as shaking of the steering wheel may be sufficient to regain the drivers attention.

- Momentary Control Intervention

If the driver does not respond to the first levels of warning, the countermeasure would initiate step inputs to the steering wheel to regain the driver's attention. This step input would be of sufficient duration to determine if the driver can control the vehicle.

- Modulate Driver Control Input

In this case, the driver has responded to the entry onto the shoulder by initiating a steering correction. This correction caused the vehicle to generate forces which exceeded the levels the shoulder could support. The vehicle transitioned to a yaw mode prior to leaving the usable roadway/shoulder. The countermeasure would modulate the steering input to the wheels upon sensing the nature and condition of the current travel surface. In this case, the steering input would be attenuated to increase the period over which the steering correction is applied. This would result in a reduction of the quick movements that led to the initial yaw. Specifically, the steering input would be attenuated to slowly bring the vehicle back onto the roadway.

4.4.2.2 Summary of Driver Inattention Causal Factor Group

The Driver Inattention group of crashes is primarily associated with the driver not being aware of the immediate surrounding environment. The countermeasure's goal is to recognize that the driver is inattentive and to then present a warning to the driver to prevent the departure. The example above, involving application of a countermeasure to these crashes, illustrates that an indication of driver inattention can be derived by observing the path of the vehicle and determining when that path will result in a departure from the roadway surface. This must be deduced by considering factors both in the vehicle, such as vehicle path and dynamic state, and in the infrastructure, such as roadway alignment and number of lanes. The presentation of a phased warning to the driver may be used to return driver attention to the driving task.

4.4.3 Relinquished Steering Control Causal Factor GrouP

The Relinquished Steering Control causal factor group accounts for 28.9 percent of the clinical sample examined. This group consists of those cases where the driver, due to impairment caused by alcohol, exhaustion, or physical illness ceases to control the vehicle, A listing of the characteristics typical of the Relinquished Steering Control group is shown in Figure 4-6. As evident in this figure, the Relinquished Steering Control causal factor occurs primarily on curved roadway segments (62.4 percent) under dry roadway conditions. The vehicle movement toward roadway departure is classified as drifting or tracking in over 99 percent of the cases: The driver's response to the controlled movement is predominantly coded as "none" (85.3 percent), although inadvertent steering input comprises a substantial proportion (14.5 percent) of the cases.

The factor of critical importance is driver state prior to the crash. In all of these cases the driver was coded as either drowsy (36.0 percent), had been drinking/driving under the influence (HBD/DUI-58.9 percent), or incapacitated (5.2 percent). These factors have a great influence on the determination of a countermeasure. In cases where the driver is drowsy, a warning may be adequate to regain the driver's attention, however, modulation of the driver's input would be required to prevent a sudden jerking of the steering wheel which often occurs when a driver is alerted from a drowsy state. In contrast, active control of vehicle systems will probably be required for cases involving driver intoxication and incapacitation. The active control would extend to the primary vehicle controls (steering, throttle, and brakes). In these cases, which compose 64 percent of the causal factor group, a warning would be insufficient because the driver is unable to take effective control of the vehicle. These cases would probably require the countermeasure to identify that the driver is unable to effectively control the vehicle and to then guide the vehicle to a safe attitude as quickly as possible.

A countermeasure designed to prevent the crashes associated with the Relinquished Steering Control causal factor group must determine the state of the driver through non-intrusive means. The state of the driver should be determined through monitoring of the manner in which the driver is manipulating the primary vehicle controls and driver reaction to the roadway situation in which the vehicle is traveling. To accomplish this, the dynamic state of the vehicle as it is traveling along the roadway would be monitored. In addition, the countermeasure would determine the configuration of the approaching roadway segment. These two critical pieces of data would be processed to determine if the driver is exercising control of the vehicle in a manner that will not result in a roadway departure.

The determination of driver state may be inferred by the manner in which the driver exercises control of the vehicle and confirmation of driver state may be obtained by determining the driver's response to warnings of impending roadway departure. The use of countermeasure functional goals to prevent a crash caused by the driver relinquishing steering control is illustrated below. The dynamic scenario from a NASS CDS case acquired in Task 1 of this program is modified to show the use of the functional goals.

Causal Factor: ***Driver Relinquished Steering Control***

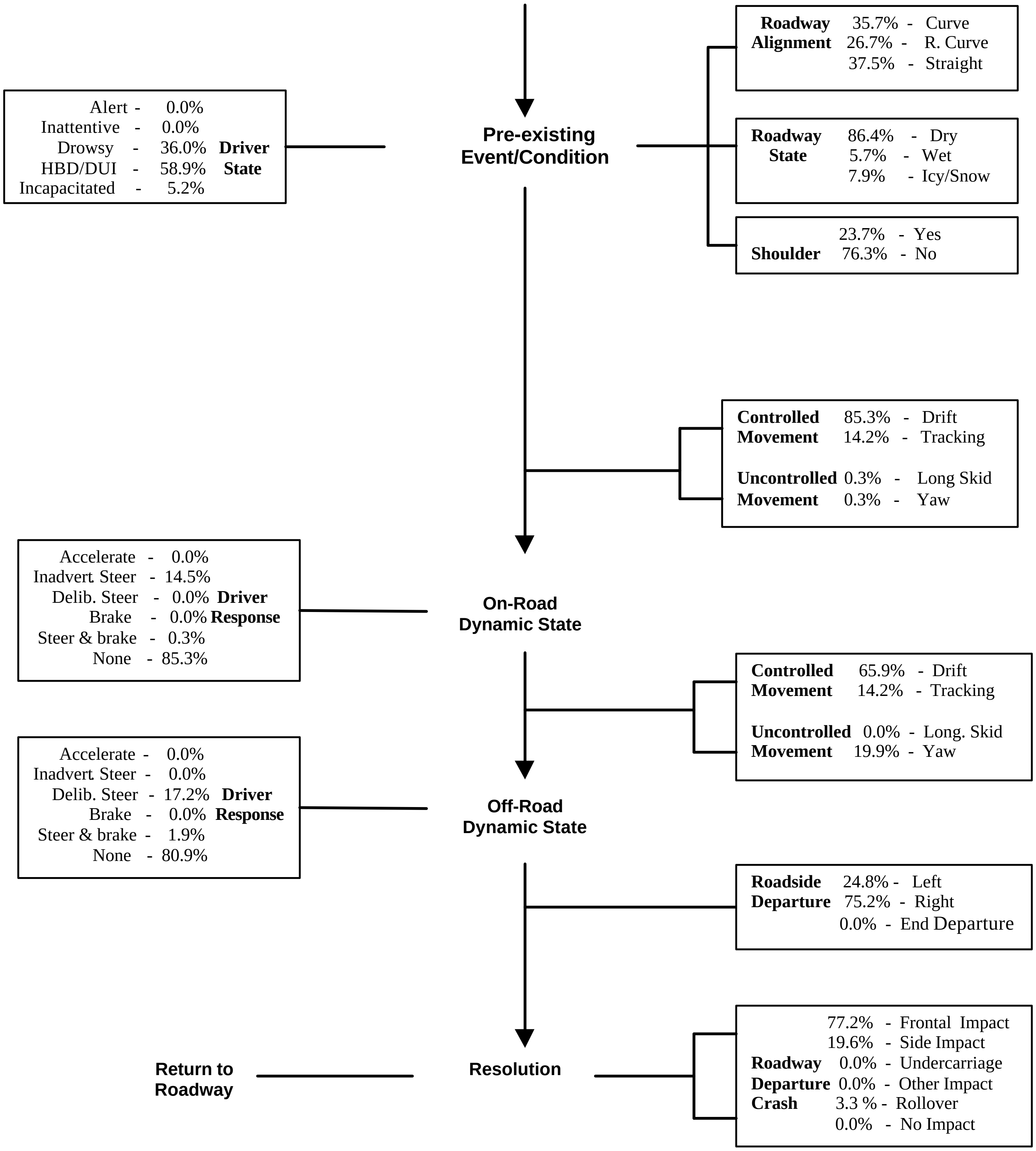


Figure 4-6 VEHICLE DYNAMIC SCENARIO ANALYSIS - DRIVER RELINQUISHED STEERING CONTROL

4.4.3.1 Relinquished Steering Control Causal Factor Group - Case No. 02-097

This accident occurred on a rural, four lane divided roadway at 12:45AM The highway was divided by a grass median. The driver of the vehicle was a 67 year-old male. The weather was clear, with some clouds, and the roadway surface condition was dry. The driver was traveling along a large radius right curve roadway segment. The driver fell asleep at the wheel. The vehicle drifted across the inboard lane and departed the inboard shoulder onto the grass median. The driver induced rapid steering maneuvers which resulted in a 90 degree counterclockwise yaw on the median. The vehicle traversed a ditch and overturned. A summary fact sheet for this case is provided in Figure 4-7. The scene diagram illustrating the roadway alignment, configuration of the roadway shoulder, and the trajectory of the vehicle as it left the roadway is presented in Figure 4-8. It is important to note in this case that the vehicle traveled along a shallow path toward the left shoulder for a period of time. This period, where the driver is on a path that ***could*** lead to a roadway departure, is when the countermeasure must operate to determine the driver's state and determine if active vehicle control should be exercised to prevent the departure.

A run-off-road countermeasure has a number of opportunities to prevent this roadway departure. As with the Driver Inattention causal factor group, the functional goals to prevent this crash are applied to the case dynamic scenario diagram. The dynamic scenario for this case is provided in Figure 4-9. Also illustrated in Figure 4-9 are the countermeasure functional goals that would be applied to prevent ***this*** crash. A discussion of the application of each of the functional goals is provided below:

- Monitor Vehicle Dynamic Status

The equipment to monitor vehicle dynamic status would be active at all times that the vehicle is operational. This equipment, which would likely be used by other collision avoidance systems, would monitor key parameters of what the vehicle is doing at any given time. Some of the parameters that the equipment would monitor are vehicle speed, heading, and the state of acceleration along the vehicle's longitudinal and lateral axes. The information provided by this suite of equipment provides part of the basic information that the on-board CPU requires to determine the potential for roadway departure.

- Determine Geometric Characteristics of Upcoming Roadway Segment

In order to determine the roadway configuration into which the vehicle is proceeding, the geometric characteristics of the roadway must be acquired. The characteristics that would be utilized in this case are described below:

a Number of lanes - This characteristic would set the maximum lateral movement of the vehicle path acceptable to prevent roadway departure. In this case, the data on-board would indicate the presence of another lane for the driver to enter.

b. Lane width - This is complementary information used to determine the extent of the vehicle's lateral path.

PSU-Case No.
02-097

CAUSAL FACTOR: *Driver Relinquishes Steering Control - Fell Asleep*

ROADSIDE DEPARTURE: *Left*

General Accident Information			
Date:	7-2-93	Weather:	Clear
Time:	0045	*Surface Condition:*	Dry
Accident Type:	Drive Off Road	Lighting:	No
Accident Severity:	2 (B)	*Land Use:*	Rural

Driver/Occupant Information		Vehicle Information	
Driver Age:	67	*Year:*	1986
Driver Sex:	Male	*Vehicle Make:*	Oldsmobile
Impairment	Fell Asleep	*Vehicle Model:*	Cutlass
Familiarity with Road:	Unknown	ABS:	No
No. of Occupants:	*1*	*Defects:*	No

Roadway Information			
Trafficway Type *(Median):*	Flush or curb	*Alignment:*	Curve Right
		Slope:	Level
No. of Lanes:	*2*	*Speed Limit:*	89 km/h

Cluster Variables	
GV14:	07 Steering right
GV64:	01 Going straight
GV65:	12 This vehicle traveling off the edge of the road on the left side
GV66:	4 Skidding laterally counterclockwise rotation
GV67:	4 Vehicle departed roadway

Calspan Corporation
Carnegie Mellon University

Run-Off-Road Collision Avoidance
Case Summary

Figure 4-7 RUN-OFF-ROAD COLLISION CASE SUMMARY
EXAMPLE OF DRIVER RELINQUISHED STEERING CONTROL
Case No. 02-097

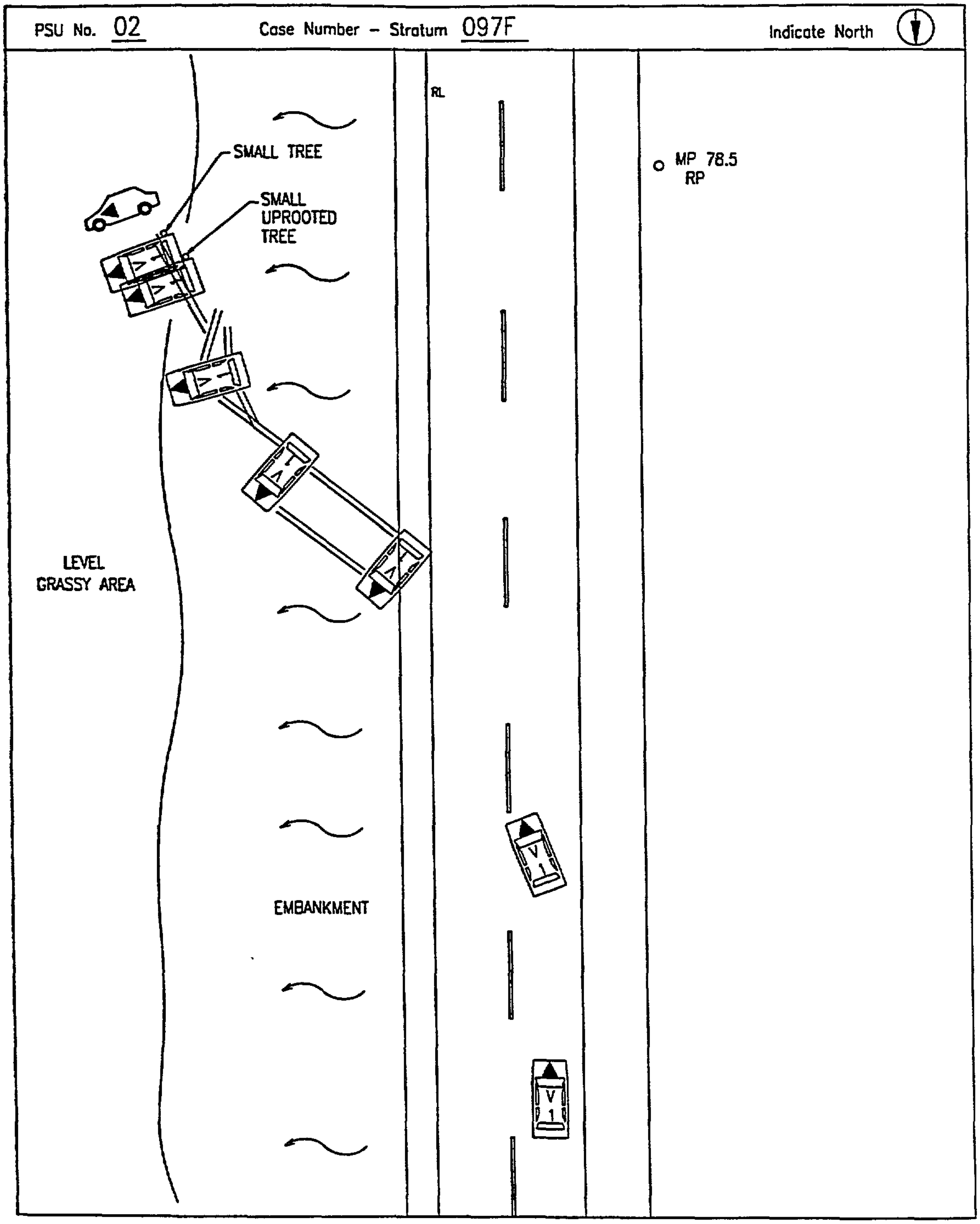
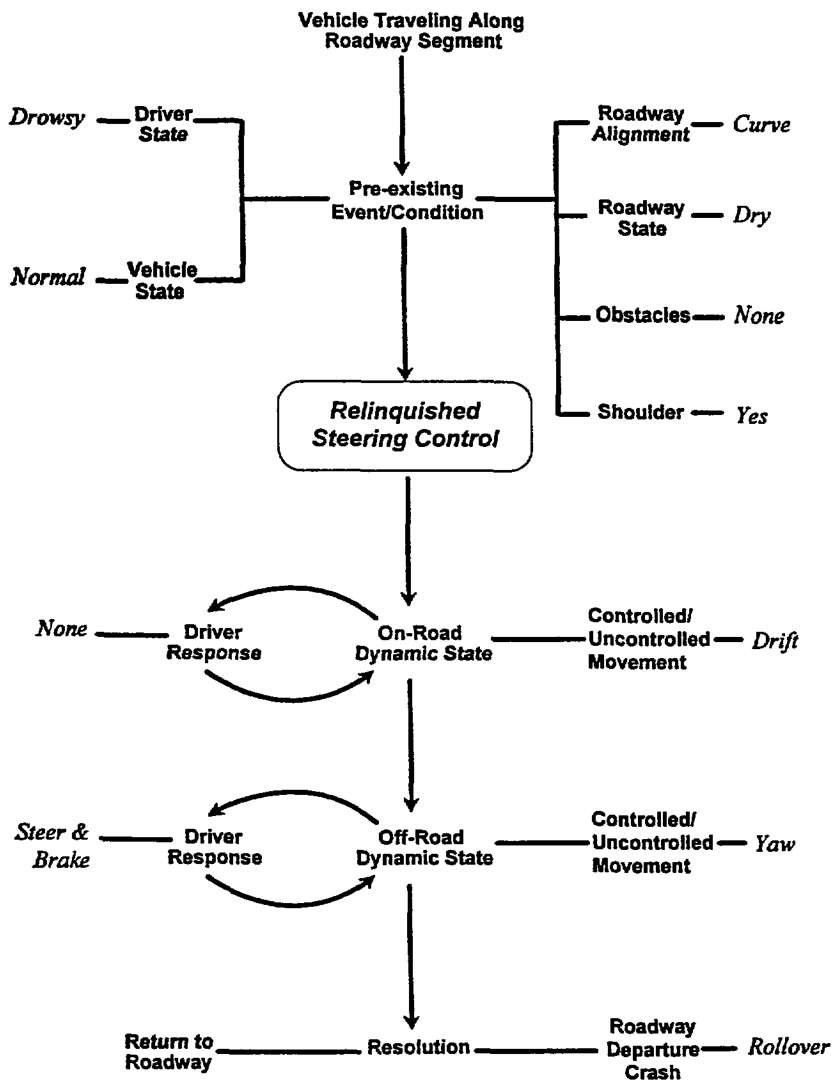


Figure 4-8 **RUN-OFF-ROAD COLLISION DIAGRAM**
EXAMPLE OF DRIVER RELINQUISHED STEERING CONTROL
Case No. 02-097

Vehicle Dynamic Scenario
Causal Factor Grouping - Driver Relinquished Steering Control

Example PSU-Case No. 02-097



Functional Goals

(1) Monitor vehicle dynamic status

(2) Determine geometric characteristics of upcoming roadway segment

(3) Determine vehicle position/ orientation relative to roadway

(9) Present alert of approaching curve geometry

(6) Process data to determine acceptable speed for approaching roadway segment

(7) Detect potential for roadway departure

(4) Determine driver intention

(11) Determine driver state

(13) Present alert of driver impairment

(15) Present warning of excessive vehicle lateral movement

(12) Modulate driver control input

(16) Momentary control intervention

(17) Safe vehicle attitude

Figure 4-9 RUN-OFF-ROAD COLLISION SEQUENCE WITH APPLIED FUNCTIONAL GOALS EXAMPLE OF DRIVER RELINQUISHED STEERING CONTROL

c. Roadway alignment - Determine if approaching roadway is straight or curved. In addition, “provide information regarding left or right curvature.

d. Curvature of roadway segment - This data would aid in the determination of an acceptable speed at which the vehicle may traverse the approaching roadway segment.

e. Roadway superelevation - Along with roadway alignment this would be used to determine an acceptable travel speed for a roadway segment.

- Determine Vehicle Position/Orientation Relative to Roadway

This functional goal would establish where the vehicle is in relation to the travel lane and the relative orientation of the vehicle’s path and roadway. On-board equipment would detect the movement of the vehicle across the inboard lane toward the roadway shoulder, In this crash the vehicle movement was a drift out of the travel lane toward the shoulder. The countermeasure would measure this drift and warn the driver if the drift would result in a departure from the travel lane. The countermeasure must differentiate between normal in-lane drift and a driver not controlling the vehicle. As with the Driver Inattention group, a system that could “learn” the habits of the driver would be advantageous in differentiating these types of behavior. The monitoring of the relative position of the vehicle within the lane could act to “arm” a driver warning or corrective action. A secondary concern with the differentiation between maneuvers is the potential for false alarms. Rules must be set to determine drift from normal lane change behavior. Without these rules, a high proportion of false alarms may degrade the effectiveness of the final countermeasure.

In this roadway departure crash, the countermeasure would have detected the drift of the vehicle. The countermeasure would determine that the vehicle’s drift to the left would result in the vehicle leaving the travel lane. The countermeasure must then determine if this a conscious maneuver by the driver, that is, a lane change or a potential roadway departure. This is not a trivial task. Since vehicle drift can have a large set of angular deviations and durations, the countermeasure must differentiate this behavior from a driver’s normal lane change maneuver. A warning would be issued to the driver when a roadway departure is probable. The substance of this warning will be discussed in a later functional goal.

- Present Alert of Approaching Curve Geometry

As in previous causal factor groups, this alert may be sufficient to prevent the crash. The relinquishing of steering control in this case is due to the driver falling asleep at the wheel. The presentation of an alert of an approaching curve may have the desirable effect of prompting the driver to regain an attentive state. The alert would be presented at a sufficient distance from the curve for the driver to adjust vehicle speed in a safe manner.

- Process Data to Determine Acceptable Speed for Approaching Roadway Segment

This functional goal provides a preview of the roadway segment that the vehicle is approaching and calculates an acceptable speed at which the vehicle may be operated. Data stored in the on-board digital map is compared with current vehicle position provided by a system such as DGPS (Differential Global Positioning System) to determine the configuration of the approaching roadway. Other information items that would be used in this functional goal are:

a. Current vehicle speed
b. Longitudinal acceleration (is the vehicle slowing or traveling at constant velocity)
c. Lateral acceleration (is the vehicle moving to another lane)
d. Characteristics of upcoming roadway segment (e.g., surface condition, curvature, etc.)

- Detect Potential for Roadway Departure

This functional goal would process data from the various sensor suites and determine the potential for roadway departure. This determination would primarily use data regarding vehicle position, roadway configuration, and vehicle dynamic status (including path) to ascertain if the vehicle will depart the roadway. If this determination is made, a phased warning is presented to the driver. In this crash, the countermeasure would recognize that the vehicle is moving to another lane due to the magnitude of the lateral acceleration. If this magnitude were above the “normal” threshold for this driver, a warning would be issued.

- Determine Driver Intention

With information available on vehicle dynamic status, position, and orientation on the roadway, a determination of driver intention may be completed by the countermeasure. The countermeasure will use data that has been previously acquired regarding the configuration of the approaching roadway segment, the acceptable speed for the approaching roadway segment, and an indicator of how well the driver is exercising control over the vehicle. This information, potentially augmented with information from other collision avoidance countermeasures, may be used to determine driver intention. In this crash, the countermeasure would not detect a rationale for the driver pulling off the roadway and could use this information as a key to issuing a warning.

- Determine Driver State

The countermeasure would determine if the driver is exercising reasonable control of the vehicle. This may be accomplished by monitoring the manner in which the driver maintains position within the lane in recent preceding time intervals, by monitoring steering correction frequency and magnitude, by monitoring velocity control variability, etc. This step is a necessary prelude to the use of active vehicle controls.

- Present Alert of Driver Impairment

The presentation of an alert may be used to aid in the determination of driver state. The various levels of alert or warning may be used to determine the level of control that the driver is able to exercise. The monitoring of the driver's response to an issued alert or warning, in conjunction with the manner in which the driver has controlled the vehicle on the previous roadway segment, can lead to an indicator of driver state. If an appropriate response is received from the driver after the first level of warning, the driver may be regarded as having regained driving focus or concentration. (NOTE: Appropriate driver responses are those responses that do not increase the potential for a roadway departure.)

- Present Warning of Excessive Vehicle Lateral Movement

As described earlier in this section, a warning with an increasing intrusion level would be presented to the driver to prevent roadway departure. In this sample case, the countermeasure would monitor vehicle position within the lane and issue a warning when roadway departure is imminent. The first level of this warning would be a passive warning that incorporates visual, audio, or both components to warn the driver of the threat of roadway departure. In this causal factor group, the drivers are lapsing into a sleep state and may be awakened to resume control of the vehicle through this first level of warning. This first level of warning would most likely be sufficient to prevent a proportion of the crashes attributed to drivers who are drowsy. The reawakening of the driver may have other implications with respect to steering control. This will be discussed in a later functional goal category.

If the first level of warning is insufficient in terms of alerting the driver to re-establish vehicle control, the second level of warning, haptic feedback, would be applied. Haptic feedback would initiate a controlled shaking of the driver's seat, steering wheel, brake pedal, or throttle pedal in an attempt to alert the driver to control the vehicle. The transition between the first and second level of warning would occur if no response to the initial warning was received from the driver. A possible driver response would be to initiate an "appropriate" steering input (i.e., an input to the steering wheel that does not accentuate a roadway departure path).

If these two levels of warning do not elicit a response from the driver, the countermeasure may consider the driver incapacitated. In 64.1 percent of this causal factor group the driver was incapacitated by alcohol or other factors. These crashes would require further levels of intrusion including momentary or full active control of primary vehicle control functions. This aspect of the warning will be discussed in a functional goal later in this section.

- Modulate Driver Control Input

In this roadway departure case the *driver* woke after having traversed the inboard travel lane, the shoulder, and having impinged upon the median. The driver responded to the entry onto the median by initiating a steering correction. This correction caused the vehicIe to yaw and subsequently overturn. The countermeasure could be used in this case to modulate the steering input upon sensing the surface type and condition. In this case, the steering input would be attenuated to increase the period over which the steering correction is applied. This would result in a reduction of the quick movements that led to the initial yaw. The steering input that caused the yaw would be attenuated to slowly bring the vehicle back onto the shoulder, and eventually the roadway.

- Momentary Control Intervention

The initial stage of active control of the vehicle is to input momentary steering control functions to the steering wheel with the intent of allowing the driver to regain control of the vehicle. A secondary function of this goal is to increase the response time available to the driver by prolongating roadway departure times. This may be accomplished by inputting small steering corrections to steer along the roadway instead of departing from it.

- Safe Vehicle Attitude

If the driver ignores the initial alerts and warnings and the vehicle is on a path to depart the roadway, the countermeasure would seek to return the vehicle to a “safe” attitude through the active use of vehicle controls. The countermeasure system would determine which actions are required to immobilize the vehicle in a safe location until the driver is able to return to the task of controlling the vehicle. This may involve complete immobilization of the vehicle if the driver is intoxicated. This functional goal requires that the condition of the driver be determined with confidence prior to allowing further operation of the vehicle.

4.4.3.2 Summary of Relinquished Steering Control Causal Factor Group

The Relinquished Steering Control group of crashes is caused primarily by the incapacitation of the driver due to a variety of factors. The countermeasure’s goal is to recognize when the driver has become incapacitated and to then present a warning to the driver to prevent the departure. In the example above, once the countermeasure determines that a potential for departure exists, the presentation of a phased warning to the driver may be used to wake the driver. If no response is received to this warning, the countermeasure would place the vehicle in a “safe” mode. This safe mode will require active control of vehicle functions. Also, a part of this procedure may involve the immobilization of the vehicle if the driver is intoxicated. This aspect of active control, while desirable and defendable, may be unacceptable to the driving public.

4.4.4 Lost Directional Control Causal Factor Group

The Lost Directional Control causal factor group accounts for 15.7 percent of the clinical sample examined. This group consists of those cases where the driver loses control of the vehicle due to degraded roadway surface conditions. The roadway degradation in these cases is caused by rain (wet surface), ice, or snow. A listing of the characteristics typical of the Lost Directional

Control group is provided in Figure 4-l 0. As evident in this figure, the Lost Directional Control causal factor occurs primarily on straight roadway segments (61.9 percent), although a significant proportion (38.1 percent) occur on curves. The roadway condition listed for these crashes was dry in only 8.6 percent of the cases. The remainder of the cases involved icy/snow covered surfaces (56.6 percent) or wet surfaces (34.8 percent). Vehicle movement in these cases indicates a significant difference for this causal factor group. In the previous causal factor groups, the on-road vehicle movement was classified as a controlled movement. In this group, the movement is predominantly an uncontrolled movement. These data indicate that the driver most likely did not make a steering input to trigger the incident. Instead, in over 97.6 percent of the cases the movement was listed as longitudinal skid (28.1 percent) or yaw (69.5 percent). The driver's response to this uncontrolled movement is to initiate a control action. Figure 4-l 0 illustrates that in approximately two-thirds of the cases (66.4 percent), the driver initiated an input to either the steering (40.4 percent), brakes (12.3 percent), or both (13.0 percent). In over thirty-three percent of the ***cases,*** the driver's response was to perform no control action. Driver state, which could lead to a lack of driver action, was coded as "alert" in 99.2 percent of the cases.

A countermeasure to prevent these crashes must determine the state of the roadway surface. This may be determined through the use of sensors on-board the vehicle, in the infrastructure, or a system with elements distributed in both. The use of countermeasure functional goals to prevent a crash caused by the driver relinquishing steering control is illustrated below. The dynamic scenario from a NASS CDS case acquired in Task 1 of this program is modified to show the use of the functional goals.

4.4.4.1 Lost Directional Control Causal Factor Group - Case No. 13-016

This accident occurred on a rural, two lane undivided roadway at 4:45PM The driver of the vehicle was a 27 year-old male. The weather was rainy, the roadway surface condition was icy and ***snow*** covered. The driver was traveling along a large radius right curve roadway segment. The driver lost directional control as he exited the curve. A summary fact sheet for this case is provided in Figure 4-l 1. The scene diagram illustrating the roadway alignment, configuration of the roadway shoulder, and the trajectory of the vehicle as it left the roadway is presented in Figure 4-12. It is important to note in this case that the vehicle traversed a curve prior to losing directional control. This may indicate that the loss of control occurred as the vehicle accelerated out of the curve. If the driver was made aware of the degraded roadway condition through the use of a countermeasure this accident could have been prevented.

A run-off-road countermeasure has a number of opportunities to prevent this roadway departure. As demonstrated for the previous causal factor groups, the applicable functional goals to prevent this crash may be applied to the dynamic scenario diagram for this case. The vehicle dynamic scenario for this case is provided in Figure 4-13. Also illustrated in Figure 4-13 are the countermeasure functional goals that would be applied to prevent ***this*** crash. A discussion of the application of each of the functional goals is provided below:

Causal Factor: ***Lost Directional Control***

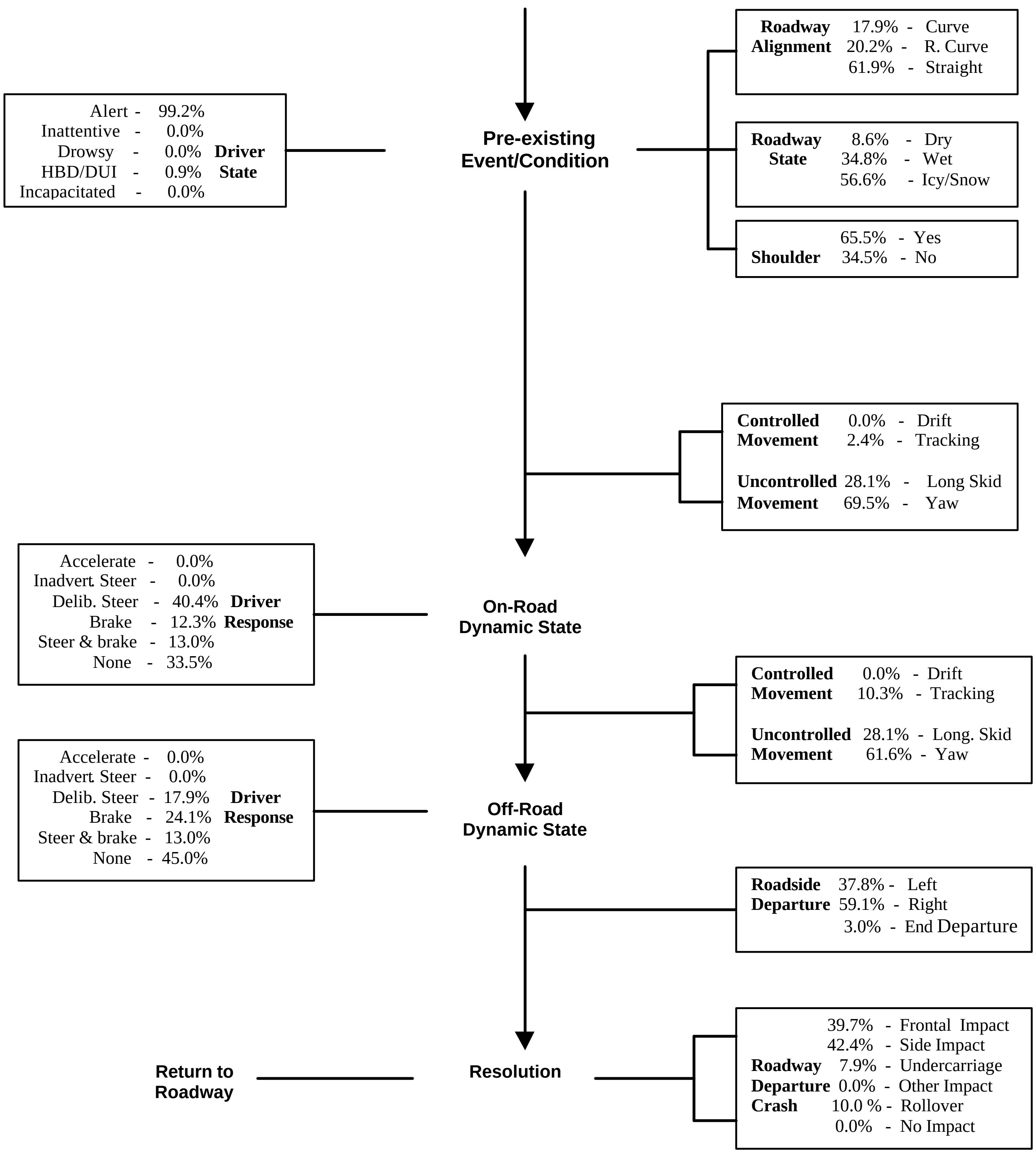


Figure 4-10 **VEHICLE DYNAMIC SCENARIO ANALYSIS LOST DIRECTIONAL CONTROL**

PSU-Case No.
13-016

CAUSAL FACTOR: ***Lost Directional Control***
ROADSIDE DEPARTURE: ***Right***

General Accident Information

Date:	1-5-93	*Weather:*	Rain
Time:	1645	Surface *Condition:*	Ice/Snow
Accident Type:	Control/Traction Loss	*Lighting:*	Daylight
Accident Severity:	0 (0)	*Land Use:*	Rural

Driver/Occupant Information

Driver Age:	27
Driver Sex:	Male
Impairment:	None
Familiarity with Road:	Unknown
No. *of Occupants:*	I

Vehicle information

Year:	1986
Vehicle Make:	Ford
Vehicle *Model:*	Ranger
ABS:	NO
Defects:	No

Roadway information

Trafficway Type *(Median):*	Not divided	*Alignment:*	Curve Left
		Slope:	Glade
No. of Lanes:	2	*Speed Limit:*	56 km/h

Cluster Variables

GV14:	99	Unknown
GV64:	13	Negotiating a curve
gv65:	05	This vehicle loss of control to poor mad Conditions
GV66:	9	Precrash stability unknown
GV6Z	9	Diectional consequences unknown

Calspan Corporation
Carnegie Mellon University

Run-Off-Road Collision Avoidance
Case Summary

Figure 4-l 1 RUN-OFF-ROAD COLLISION CASE SUMMARY EXAMPLE OF LOST DIRECTIONAL CONTROL Case No. 13-016

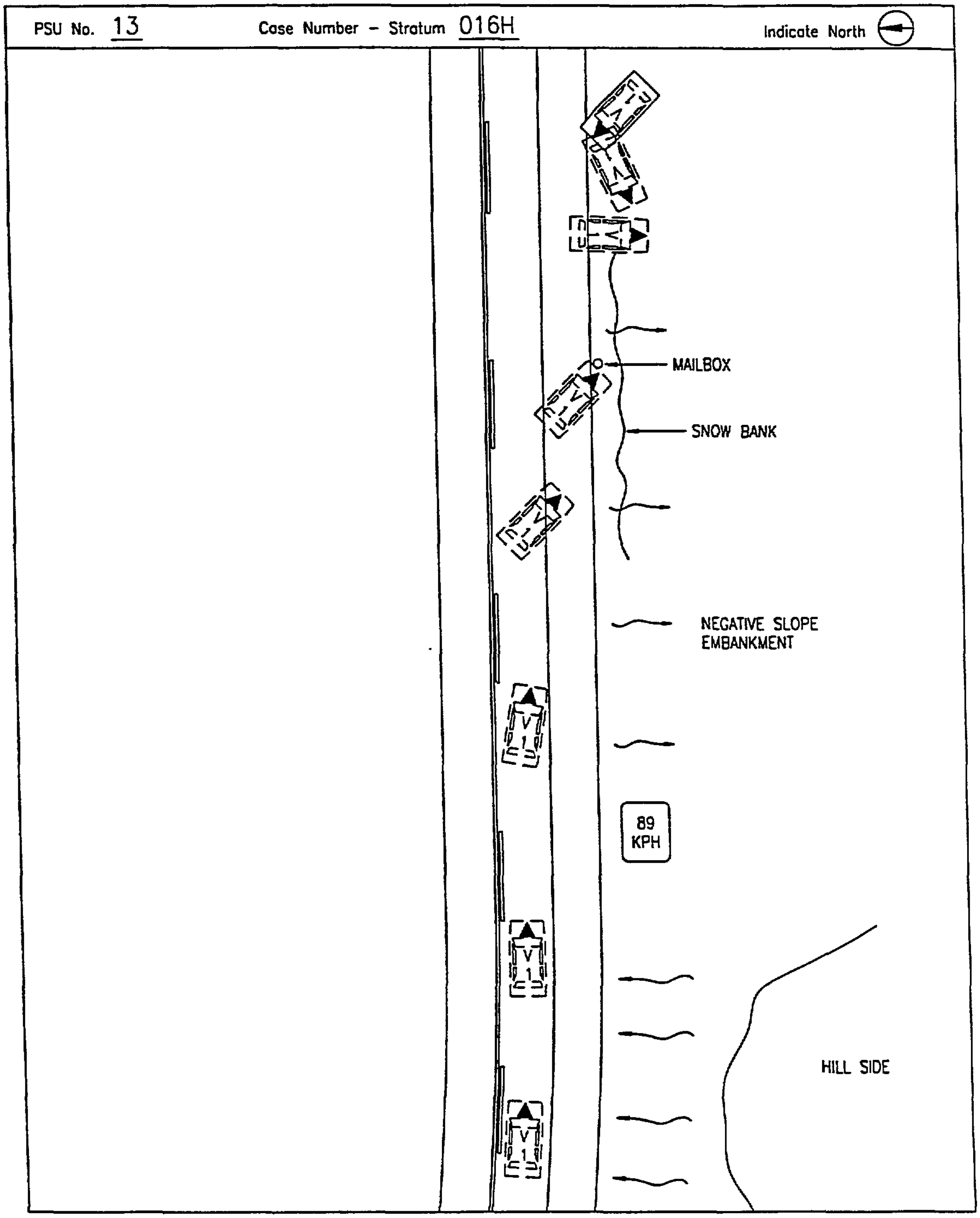
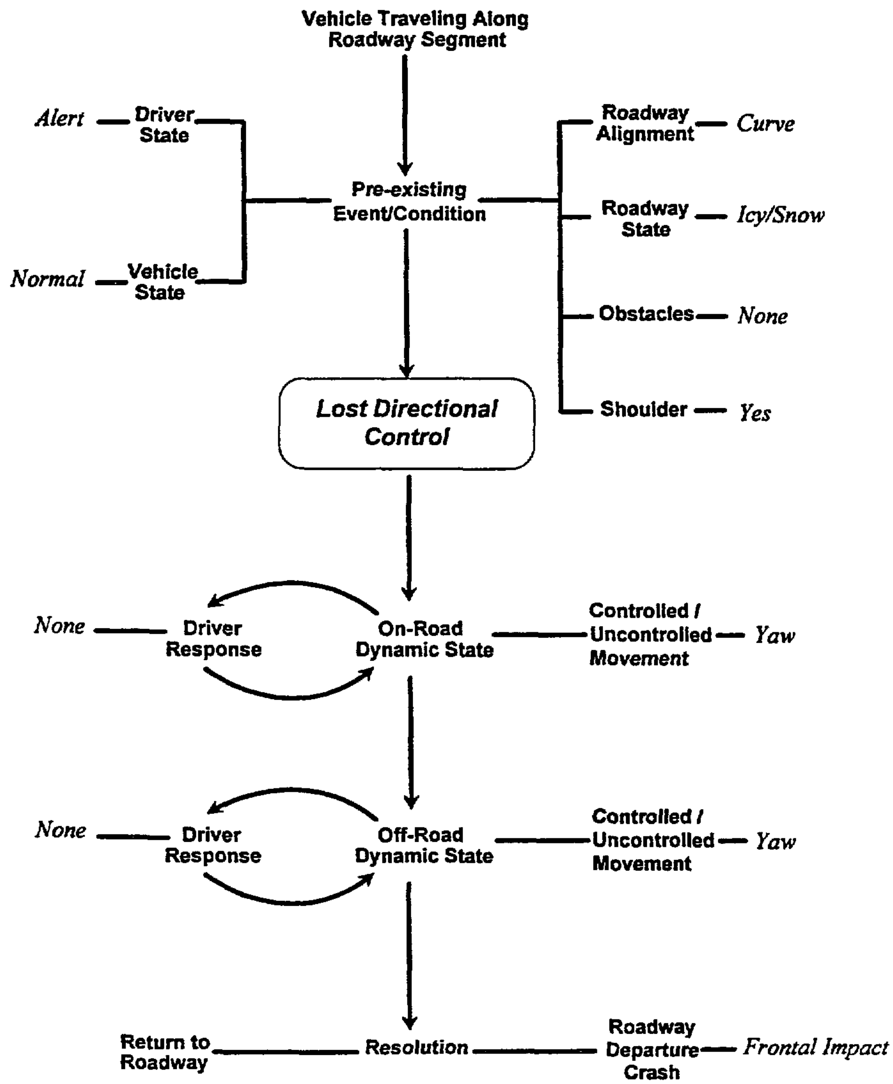


Figure 4-12 RUN-OFF-ROAD COLLISION DIAGRAM EXAMPLE OF LOST DIRECTIONAL CONTROL Case No. 13-016

Vehicle Dynamic Scenario
Causal Factor Grouping - Lost Directional Control

Example PSU-Case No.
13-016



Functional Goals

(1) Monitor vehicle dynamic status

(2) Determine geometric characteristics of upcoming roadway segment

(3) Determine vehicle position/ orientation relative to roadway

(9) Present alert of approaching curve geometry

(5) Detect degraded roadway condition

(8) Present alert of degraded roadway condition

(6) Process data to determine acceptable speed for approaching roadway segment

(10) Present alert of excessive speed for approaching curve geometry

(7) Detect potential for roadway departure

(14) Present warning of excessive speed

(4) Determine driver intention

(12) Modulate driver control input

Figure 4-13 RUN-OFF-ROAD COLLISION SEQUENCE WITH APPLIED FUNCTIONAL GOALS EXAMPLE OF LOST DIRECTIONAL CONTROL

- Monitor Vehicle Dynamic Status

The equipment to monitor vehicle dynamic status would be active at all times that the vehicle is operational. This equipment, which would likely be used by other collision avoidance systems, would monitor key parameters of what the vehicle is doing at any given time. Some of the parameters that the equipment would monitor are vehicle speed, heading, and the state of acceleration along the vehicle's longitudinal and lateral axes. The information provided by this suite of equipment provides part of the basic information that the on-board CPU requires to determine the potential for roadway departure.

- Determine Geometric Characteristics of Upcoming Roadway Segment

In order to determine the roadway configuration into which the vehicle is proceeding, the geometric characteristics of the roadway must be acquired. The characteristics that would be utilized in this case are described below:

a. Number of lanes - This characteristic would set the maximum lateral movement of the vehicle path acceptable to prevent roadway departure.

b. Lane width - This is complementary information used to determine the extent of the vehicle's iateral path.

c. Roadway alignment - Determine if approaching roadway is straight or curved. In addition, provide information regarding left or right curvature.

d. Curvature of roadway segment - This data would aid in the determination of an acceptable speed at which the vehicle may traverse the approaching roadway segment.

e. Roadway superelevation - Along with roadway alignment this would be used to determine an acceptable travel speed for a roadway segment.

- Determine Vehicle Position/Orientation Relative to Roadway

Tbis functional goal would establish where the vehicle is in relation to the travel lane and the relative orientations of the vehicle's path and roadway. On-board equipment would detect the variation in vehicle path relative to the roadway that occurred as the vehicle initiated the "fish-tailing". The countermeasure would be able to measure this variation in path and warn the driver if the current path would result in a departure of the travel lane.

- Present Alert of Approaching Curve Geometry

The presentation of an alert of an approaching curve, operating in concert with the alert for adverse roadway conditions, would allow the driver to adjust the vehicle's speed prior to a dangerous situation arising. This alert would be presented at a sufficient distance from the curve for the driver to adjust vehicle speed in a safe manner.

- Detect Degraded Roadway Condition

The detection of a degraded condition of the roadway, in this case the icy/snow covering, is key to prevention of this crash. The sensors, on-board the vehicle or in the infrastructure, must detect the presence of the ice and snow, or the presence of the conditions under which these attributes may occur.

- Present Alert of Degraded Roadway Condition

Once the countermeasure has detected the degraded condition of the roadway, an alert would be presented to the driver. This alert may present a recommended action to be taken by the driver, such as decelerating. This alert would be presented to the driver with an indication of situation immediacy, allowing the driver to react and adjust the vehicle state in a safe manner.

- Process Data to Determine Acceptable Speed for Approaching Roadway Segment

This functional goal provides a preview of the roadway segment that the vehicle is approaching and calculates an acceptable speed at which the vehicle may be operated. Data stored in the on-board digital map is compared with current vehicle position provided by a system such as DGPS (Differential Global Positioning System) to determine the configuration of the approaching roadway segment. Other information items that would be used in this functional goal are:

a. Current vehicle speed
b. Roadway condition
c. Characteristics of upcoming roadway segment (e.g., curvature, superelevation, etc.)

In this crash, the countermeasure would combine the data regarding vehicle dynamic state, configuration of roadway segment, and condition of the roadway surface to determine an acceptable travel speed for the vehicle. If the vehicle speed is in excess of the recommended speed for the roadway segment, an alert would be issued to the driver.

- Present Alert of Excessive Speed for Approaching Curve Geometry

The acceptable vehicle travel speed, determined in the functional goal listed above, would be presented to the driver. The mode of transmission of this information may be auditory, through an advisory of the suggested maximum speed for the approaching segment or visual, through icons relating this information.

- Detect Potential for Roadway Departure

This functional goal would process the data from the various sensor suites and determine the potential for roadway departure. This determination would primarily use data regarding vehicle position, roadway configuration, and vehicle dynamic status (including path) to ascertain if the vehicle will likely depart the roadway. If this determination is made, a phased warning is presented to the driver.

- Determine Driver Intention

As it would apply to this case, this countermeasure function would determine if the driver was reacting to the warning or alerts provided by the system. This function would process data regarding the potential for roadway departure and monitor if the driver is responding by inputting the proper vehicle control action. In this case, the system would monitor if the driver is adjusting vehicle speed in accordance with the alert of degraded conditions. If the driver does not respond, the countermeasure could initiate control actions to slow the vehicle to an acceptable speed for the conditions. A modulation of the driver‘s input to the steering and throttle may also follow this function.

- Momentary Control Intervention

A momentary intervention input to the throttle/brake controls could have been utilized in this case to prevent the roadway departure. In this crash, the driver was alert, but was entering the curve at a speed that was too high for the prevailing conditions. The countermeasure, utilizing functional goals such as detect roadway geometry, degraded&roadway condition, vehicle path, or vehicle speed and dynamic status, could issue an alert of an inappropriate speed for the conditions. This could be manifested by momentary application of the brakes to slow the vehicle to an acceptable speed and notification to the driver with respect to an appropriate avoidance action.

- Modulate Driver Control Input

The modulation of driver control inputs could directly prevent this crash. With the information acquired by the sensors on-board the vehicle (vehicle dynamic state, roadway configuration) and in the infrastructure (degraded roadway condition), the appropriate travel speed for the conditions may be determined. If the driver is initiating control functions to exceed the advisory travel speed, this countermeasure goal could modulate the brakes and throttle to adjust the vehicle’s speed until it is within an acceptable range. This technology has contemporary counterparts. Traction control and anti-lock brake systems are used to modulate the drivers control inputs to allow greater vehicle control. Traction control systems function by monitoring the spinning of each wheel. If one wheel starts to spin faster than the other wheels, the system concludes that it has lost traction and applies braking force to the wheel with the excess spinning. The technology discussed in this functional goal represents a growth of this system. In addition to monitoring wheel spin, the countermeasure would use other factors to determine if the wheels are spinning too fast for the conditions.

The application of this functional goal to the sample case results in the countermeasure being aware of the icy/snow covered roadway and issuing a warning to the driver. As the driver exited the curve, the system would modulate his input to the throttle until the vehicle's velocity was less than or equal to the advisory speed. This modulation would be manifested by eliminating the vehicle acceleration if the vehicle is above the advisory speed, or by lengthening of the period of acceleration if the vehicle is below the advisory speed. The lengthening of the acceleration period would eliminate the sudden application of power to the wheels that is most often associated with loss of traction.

4.4.4.2 Summary of Lost Directional Control Causal Factor Group

The loss of directional control group of crashes is caused primarily by the non-recognition by the driver of a degraded roadway condition. The countermeasure's goal is to recognize the degraded roadway surface condition and to transmit that information to the driver. In the example case above, the countermeasure determines that a degraded roadway condition exists and presents a warning to the driver. The warning may be in the form of an advisory of an appropriate travel speed If the driver is traveling above the advisory speed, the control inputs by the driver, primarily throttle and brakes, would be modulated to bring the vehicle within the advisory speed. Specific to the sample case, the acceleration of the vehicle after exiting the curve would be attenuated or eliminated.

Some degree of variability will occur in the approach utilized for crashes in this group. For example, it is anticipated that modulation of the driver's steering input would be utilized in a number of cases to allow the driver to regain control of the vehicle.

4.4.5 Vehicle Speed Causal Factor Group

The Vehicle Speed causal factor group comprises the largest proportion (39.1 percent) of the run-off-road crash sample examined. This group consists of cases where the driver loses control of the vehicle due to operating the vehicle at a speed that is excessive for prevailing conditions. Contributory factors to this crash group are degraded roadway conditions, roadway configuration, and driver impairment (primarily alcohol). It should be noted that a driver may be operating the vehicle within the posted speed limit and yet be in excess of a safe speed for the roadway configuration or prevailing conditions. For example, a curve that may be safely traversed at 45 mph when dry may be unsafe when covered with snow or ice. A listing of the characteristics typical of the Vehicle Speed group is provided in Figure 4-14. As evident in this figure, the Vehicle Speed causal factor occurs more frequently on curved roadway segments (56.7 percent), although a significant proportion (43.3 percent) do occur on straight segments. There is an interesting non-

Causal Factor: ***Vehicle Speed***

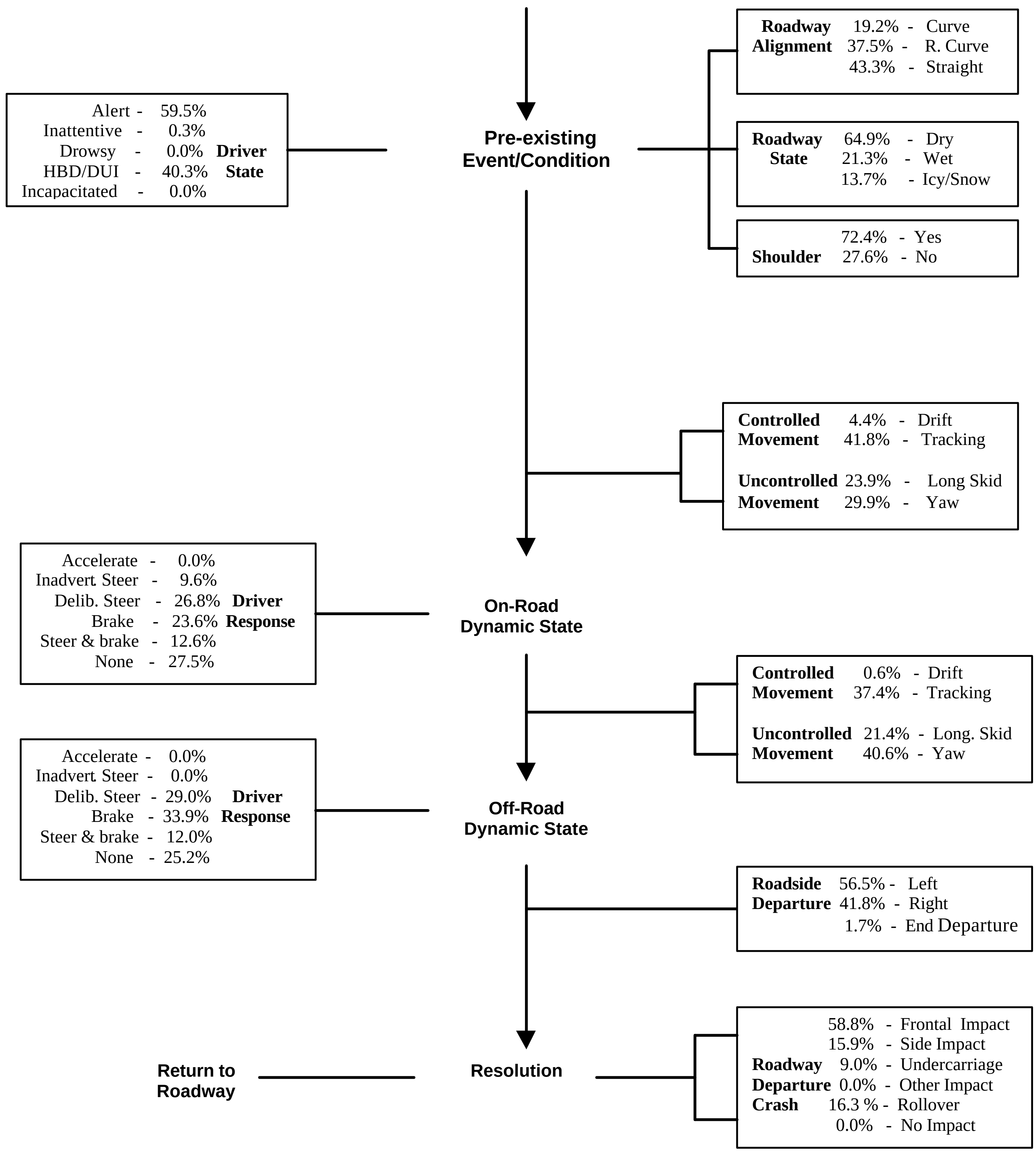


Figure 4-14 VEHICLE DYNAMIC SCENARIO ANALYSIS VEHICLE SPEED

symmetry in the distribution of crashes occurring on curves. More than twice as many crashes occur on right curves as compared to left curves (37.5 vs 19.2 percent, respectively). This may be a sample-induced asymmetry related to having an insufficient number of samples to balance the data. The roadway condition listed for these crashes is dry in 64.9 percent of the cases with the remainder of the sample being icy/snow covered (13.7 percent) or wet (21.3 percent).

The on-road vehicle movement in many of these cases is approximately evenly split between controlled and uncontrolled movement (46.2 vs. 53.8 percent, respectively). This balance in the data indicates that the driver made a control input to trigger the crash in almost half the cases. This diversity in vehicle movement prior to the crash is unified by the causal factor in these crashes; vehicle speed. In all these cases the vehicle is operated at a speed in excess of the level that the roadway configuration or surface condition can support.

The status of the driver in many of these cases must be considered as a contributory cause for the crash. In 40.3 percent of the crashes, the driver had been drinking (HBD) or was driving under the influence (DUI). A countermeasure developed to prevent these crashes must either recognize that the driver is impaired or that the speed at which the vehicle is being operated is inappropriate for the roadway configuration or conditions. The use of countermeasure functional goals to prevent a crash caused by excessive vehicle speed is illustrated below. The dynamic scenario from a NASS CDS case acquired in Task 1 of this program is modified to show the use of the functional goals.

4.4.5.1 *Vehicle Speed Causal Factor Group - Case No. 08-018*

This accident occurred on a rural, two lane undivided roadway at 5:42 PM. The driver of the vehicle was a 16 year-old male. The weather was clear with scattered clouds. The roadway surface condition was dry. The driver was traveling at a high rate of speed along a left curve roadway segment. The radius of the curve was 102 meters. The posted speed limit for the curve was 35 mph. The driver entered the curve at a high rate of speed and was unable to maintain control on the roadway. The vehicle exited the curve on the right edge, crossed the two foot wide flush, paved shoulder, and struck the guardrail with the right front quarter of the vehicle. The vehicle rebounded back onto the roadway where the driver regained control. A summary fact sheet for this case is provided in Figure 4-l 5. The scene diagram illustrating the roadway alignment, configuration of the roadway shoulder, and the trajectory of the vehicle as it left the roadway is presented in Figure 4-16. The objective of the countermeasure in this case would be to warn the driver of the inappropriate speed for the roadway configuration, and potentially to modulate the drivers control inputs to prevent the loss of control.

A run-off-road countermeasure has a number of opportunities to prevent this roadway departure. As demonstrated for the previous causal factor groups, the applicable functional goals to prevent this crash may be applied to the dynamic scenario diagram for this case. The vehicle dynamic scenario for this case is provided in Figure 4-17. Also illustrated in Figure 4-17 are the countermeasure functional goals that would be applied to prevent *this* crash. A discussion of the application of each of the functional goals is provided below:

PSU-Case No.
08-018

CAUSAL FACTOR: ***Vehicle Speed - Excessive***

ROADSIDE DEPARTURE: ***Right***

General Accident Information

Date:	*1-3-93*	*Weather*	Clear/Cloudy
Time	*1742*	*Surface Condition:*	Dry
Accident Type:	*Control/Traction Loss*	*Lighting:*	Daylight
Accident Severity:	0 (0)	*Land Use:*	Rural

Driver/Occupant Information

Driver Age:	16
Driver Sex:	Male
Impairment:	None
Familiarity with Road:	Unknown
No. of Occupants:	1

Vehicle Information

Year:	1975
Vehicle Make:	Ford
Vehicle Model:	Mustang/ Mustang II
ABS:	No
Defects:	No

Roadway Information

Trafficway Type (Median):	Not divided	*Alignment:*	Curve Left
		Slope:	Grade
No. of Lanes:	2	*Speed Limit:*	56 kph

Cluster Variables

GV14:	*06* Steering Left
GV64:	*13* Negotiating a curve
GV65:	*06* This vehicle loss of control due to traveling too fast for conditions
GV66:	*01* Tracking
GV67:	*04* Vehicle departed roadway

Calspan Corporation
Carnegie Mellon University

Run-Off-Road Collision Avoidance
Case Summary

Figure 4-15 RUN-OFF-ROAD COLLISION CASE SUMMARY EXAMPLE OF VEHICLE SPEED Case No. 08-018

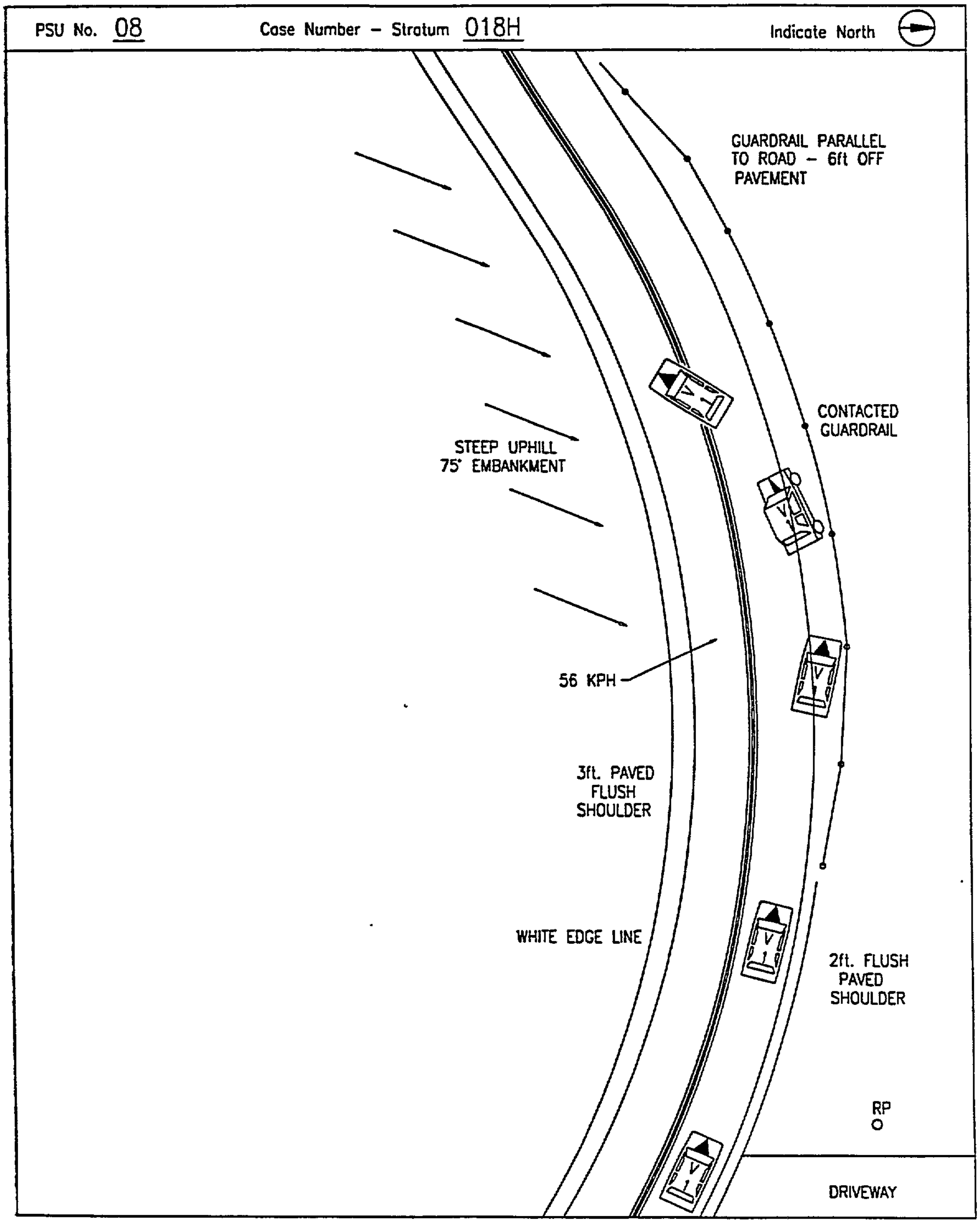
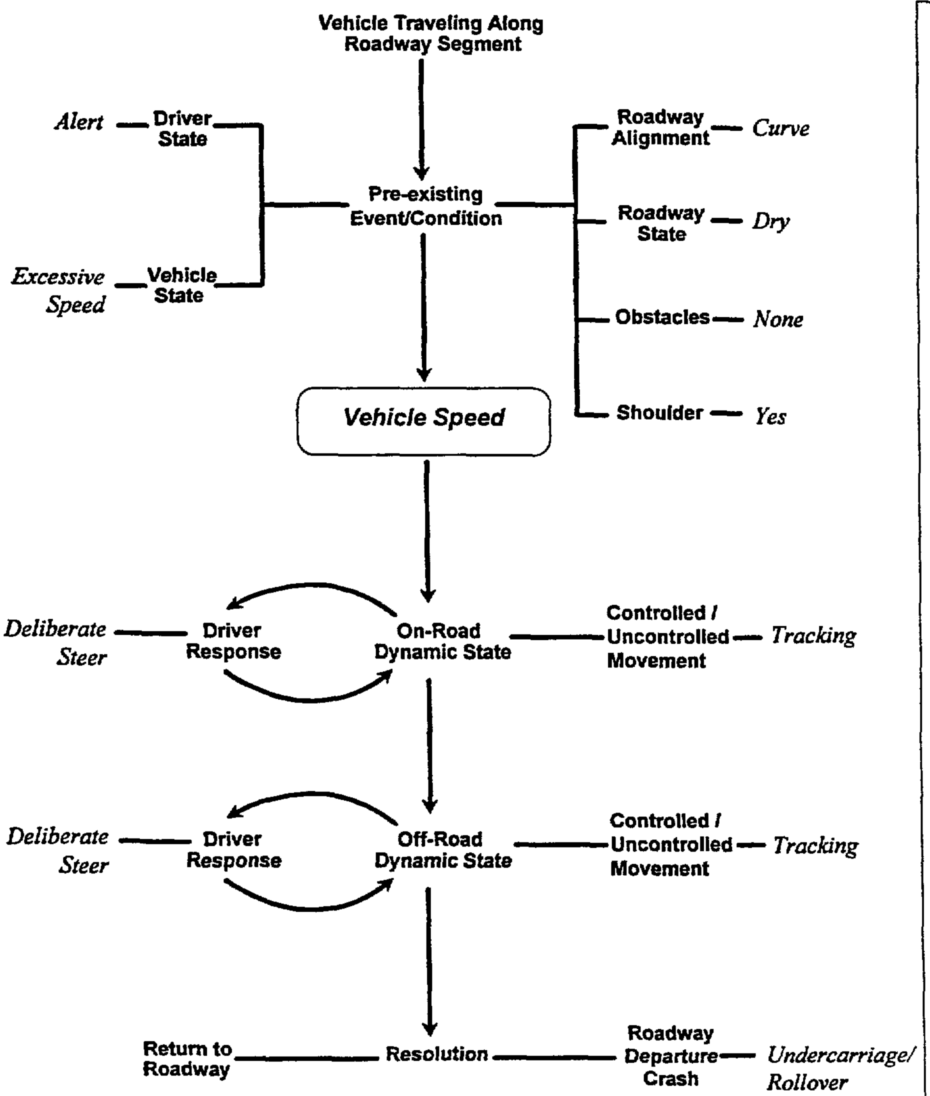


Figure 4-16 RUN-OFF-ROAD COLLISION DIAGRAM EXAMPLE OF VEHICLE SPEED Case No. 08-018

Vehicle Dynamic Scenario
Causal Factor Grouping - Vehicle Speed

Example PSU-Case No. 08-018



Functional Goals

(1) Monitor vehicle dynamic status

(2) Determine geometric characteristics of upcoming roadway segment

(3) Determine vehicle position/ orientation relative to roadway

(9) Present alert of approaching curve geometry

(6) Process data to determine acceptable speed for approaching roadway segment

(10) Present alert of excessive speed for approaching curve geometry

(7) Detect potential for roadway departure

(4) Determine driver intention

(14) Present warning of excessive speed

(12) Modulate driver control input

Figure 4-17 RUN-OFF-ROAD COLLISION SEQUENCE WITH APPLIED FUNCTIONAL GOALS EXAMPLE OF VEHICLE SPEED

- Monitor Vehicle Dynamic Status

The equipment to monitor vehicle dynamic status would be active at all times that the vehicle is operational. This equipment, which would likely be used by other collision avoidance systems, would monitor key parameters of what the vehicle is doing at any given time. Some of the parameters that the equipment would monitor are vehicle speed, heading, and the state of acceleration along the vehicle's longitudinal and lateral axes. The information provided by this suite of equipment provides part of the basic information that the on-board CPU requires to determine the potential for roadway departure.

- Determine Geometric Characteristics of Upcoming Roadway Segment

In order to determine the roadway configuration into which the vehicle is proceeding, the geometric characteristics of the roadway must be acquired. The characteristics that would be utilized in this case are described below:

a. Number of lanes - This characteristic would set the maximum lateral movement of the vehicle path acceptable to prevent roadway departure.

b. Lane width - This is complementary information used to determine the extent of the vehicle's lateral path.

c. Roadway alignment - Determine if approaching roadway segment is straight or curved. In addition, provide information regarding left or right curvature.

d. Curvature roadway segment - This data would aid in the determination of an acceptable speed at which the vehicle may traverse the approaching roadway segment.

e. Roadway superelevation - Along with roadway alignment this would be used to determine an acceptable travel speed for a roadway segment.

- Determine Vehicle Position/Orientation Relative to Roadway

This functional goal would establish where the vehicle is in relation to the travel lane and the relative orientations of the vehicle's path and roadway. On-board equipment would detect the variation in vehicle path relative to the roadway that occurs as the vehicle runs wide in the turn The countermeasure would measure this variation in path and warn the driver if the variation would result in a departure of the travel lane.

- Present Alert of Approaching Curve Geometry

The presentation of an alert of an approaching curve could allow the driver to adjust the vehicles' speed prior to the dangerous situation arising. This alert would be presented at a sufficient distance from the curve for the driver to adjust vehicle speed in a safe manner.

- Process Data to Determine Acceptable Speed for Approaching Roadway Segment

This functional goal provides a preview of the roadway segment that the vehicle is approaching and calculates an acceptable speed at which the vehicle may be operated. Data stored in the on-board digital map is compared with current vehicle position provided by a system such as DGPS (Differential Global Positioning System) to determine the configuration of the approaching roadway segment. Other information items that would be used in this functional goal are:

a. Current vehicle speed
b. Roadway condition
c. Characteristics of upcoming roadway segment (e.g., curvature, superelevation, etc.)

In this crash, the countermeasure would combine the data regarding vehicle dynamic state, configuration of the roadway segment, and condition of the roadway surface to determine an acceptable travel speed for the vehicle. If the vehicle speed is in excess of the recommended speed for the roadway, an alert would be issued to the driver.

- Present Alert of Excessive Speed for Approaching Curve Geometry

The acceptable vehicle travel speed, determined in the functional goal listed above, would be presented to the driver. The transmission mode of this information may be auditory, through an advisory of the suggested maximum speed for the approaching segment or visual, through icons relating this information. This alert would be issued to the driver in a timely manner so that extreme vehicle maneuvers are not required. In the sample case, this alert would have been issued in conjunction with the alert for the approaching curve.

- Detect Potential for Roadway Departure

This functional goal would process the data from the various sensor suites and determine the potential for roadway departure. This determination would primarily use data regarding vehicle position, roadway configuration, and vehicle dynamic status (including path) to ascertain if the vehicle will depart the road. If this determination is made, a phased warning is presented to the driver.

- Determine Driver Intention

In this crash the countermeasure would process data on the vehicle dynamic state (vehicle speed and is the vehicle decelerating to a speed appropriate for the roadway segment), roadway configuration/characteristics (curved roadway segment, direction of the curve, radius of curve, superelevation of curve, number of travel lanes), and determination of an appropriate speed for the segment. This data may be used to determine if the driver is acting in an appropriate manner for the approaching roadway segment.

- Present Warning of Excessive Speed

The countermeasure would issue a warning to the driver of excessive speed when the time available to adjust the speed in a controlled manner reaches a critical minimum value. This critical minimum value would be velocity-dependant and would allow the driver to respond without using high levels of braking.

- Momentary Control Intervention

A momentary intervention input to the throttle/brake controls could have been utilized in this case to prevent the roadway departure. In this crash, the driver was alert, but was entering the curve at a speed that was too high for the roadway geometry. The countermeasure, utilizing functional goals such as detect roadway geometry, vehicle path, or vehicle speed and dynamic status, could issue an alert of an inappropriate speed for the roadway geometry. This alert could be manifested by momentary application of the brakes to slow the vehicle to an acceptable speed and notification to the driver with respect to an appropriate avoidance action.

- Modulate Driver Control Input

The modulation of the driver's control inputs could directly prevent this crash. With the information acquired by the sensors on the vehicle (vehicle dynamic state, roadway configuration) and in the infrastructure (degraded roadway condition), the appropriate travel speed for the conditions may be determined. If the driver is initiating control functions to exceed the advisory travel speed, this functional goal could modulate the brakes and throttle to adjust the vehicle's speed until it is within an acceptable range. This technology has contemporary counterparts. Traction control and anti-lock brake systems are used to modulate driver control inputs to allow greater vehicle control. Traction control systems function by monitoring the spinning of each wheel. If one wheel starts to spin faster than the other wheels, the system concludes that it has lost traction and applies braking force to the wheel with excess spinning. The technology discussed in this functional goal represents a growth of this system. In addition to monitoring wheel spin, the countermeasure would use other factors to determine if the wheels are spinning too fast for the conditions.

Application of this functional goal to the sample case requires that the countermeasure be aware of the roadway configuration and issue an alert to the driver. As the driver approached the curve, the system would modulate his input to the throttle until the vehicle's velocity was less than or equal to the advisory speed. If the driver attempted to over-ride the system by applying more force to the accelerator pedal, the countermeasure would increase the force required to depress the pedal thus, indicating an excessive speed condition.

4.4.5.2 Summary of Vehicle Speed Causal Factor Group

The Vehicle Speed group of crashes is typically associated with drivers operating vehicles in excess of safe speeds in degraded roadway conditions. A significant portion of these crashes occur without adverse conditions, but with operation at an unsafe speed. In the sample case cited, no degraded condition existed. The countermeasure's goal in this causal factor group is to:

- Determine the configuration of the roadway segment.
- Recognize a degraded roadway surface condition.
- Determine a safe speed at which to traverse the roadway segment.
- Transmit roadway information to the driver.
- Determine driver intention.
- Modulate driver control to maintain safe vehicle attitude.

In the sample case above, the countermeasure would determine the roadway configuration, determine a safe speed for the segment, and present a warning to the driver. The warning may be in the form of an advisory of an appropriate travel speed. If the driver is traveling above the advisory speed, the control inputs by the driver, primarily throttle and brakes, would be modulated to bring the vehicle within the advisory speed.

In this causal factor group, a proportion of the cases could also be prevented by the application of additional functional goals. For example, the ability to determine the driver's state and issue a warning of an impaired state could apply to approximately 40 percent of the crashes. This utilization of additional functional goals will be discussed in Section 5.0

4.5 Summary of Countermeasure Functional Goals

In this section an examination of the functional goals for a run-off-road countermeasure was presented. The functional goals were applied to four causal factor groups consisting of 166 cases drawn from the NASS CDS clinical sample prepared in Task 1 of this program. This methodology produced separate "sets" of countermeasure functional goals that may be utilized to prevent each type of crash. The implications of these countermeasure functions are examined in Section 5.0 of this report.

5.0 Functional Goal Utilization

Section 4.0 documented a set of functional goals that would prevent or mitigate the severity of run-off-road crashes. These goals were actions, warnings, or data processing functions that the countermeasure would perform to allow the driver to avoid the collision. The identified functional goals relied on sensors on-board the vehicle (and potentially in the infrastructure) to detect critical features of the vehicle, driver and roadway. These data would be processed by computers on-board the vehicle to determine the potential for roadway departure. Examples of the data that would be acquired by the countermeasure are:

- Vehicle dynamic state (velocity, acceleration, heading)
- Roadway configuration (number of lanes, horizontal alignment)
- Vehicle position on roadway
- Condition of roadway surface
- Driver control of vehicle

The set of functional goals was derived by utilizing the causal factor groups identified in the clinical analysis sequence completed for Task 1. The Task 1 effort produced a taxonomy for run-off-road crashes that classified individual cases by the cause of the crash. These causal factor groups were then reviewed to develop a set of characteristics that were considered to-be important features of the crashes. The functional goal evaluation sequence for these causal factor groups considered all relevant features of the groups in functional goal utilization. This evaluation illustrated that the groups contained common features that could be detected by a suite of countermeasure equipment. The countermeasure would operate by detecting these features and either issuing a warning to the driver or by exercising direct control of the vehicle. Each causal factor group produced a set of functional goals that would be utilized to prevent crashes in that group. The final set of goals is a combination of the goals applicable to each group. Functional goals that were used in a small proportion of the cases were examined and evaluated to determine if the indicated utilization rates were sufficient to warrant including these goals in the final set of goals.

Table 5-l illustrates the utilization of individual functional goals in the four causal factor groups considered in this program. These causal factor groups were derived from the NASS CDS clinical sample established in Task 1 of tbis program. The causal factor groups examined in this analysis accounted for 161 of the 201 cases contained in the clinical sample. Each causal factor group was reviewed to determine the functional goals that would be utilized in the prevention of these crashes. As part of this process, key parameters contained in the case files, that were related to the utilization of each goal, were identified. The set of cases comprising the causal factor group was then scanned to determine the presence of these keys. The individual cells in Table 5-l contain the proportion of cases in each group that utilize the referenced functional goal. Thus, summation of the utilization of the functional goals across the four causal factor groups provides an assessment regarding the value of individual functional goals. Two important points should be noted in this table. First, five functional goals are used in all cases. These five goals form the basis of run-off-road countermeasures and may be summarized as follows:

- Monitor vehicle dynamic status.
- Determine geometric characteristics of approaching roadway segment.
- Determine vehicle position/orientation relative to roadway.
- Determine driver intention.
- Detect potential for roadway departure.

Table 5-1
Utilization of Functional Goals
in the
Run-Off-Road Collision Sample

Functional Goal	Causal Factor Group			
	Driver Inattention	Relinquished Steering Control	Lost Directional Control	Vehicle Speed
(1) Monitor vehicle dynamic status	100.0%	100.0%	100.0%	100.0%
Determine geometric characteristics of upcoming roadway segment	100.0%	100.0%	100.0%	100.0%
(2) Determine vehicle position/orientation relative to roadway	100.0%	100.0%	100.0%	100.0%
(4) Determine driver intention	100.0%	100.0%	100.0%	100.0%
(5) Detect degraded roadway condition	0.0%	100.0%	100.0%	100.0%
(6) Process data to determine acceptable speed for approaching roadway segment	7.4%	2.1%	7.7%	100.0%
(7) Detect potential for roadway departure	100.0%	100.0%	100.0%	100.0%
(8) Present alert of degraded roadway condition	0.0%	20.8%	92.3%	29.2%
(9) Present alert of approaching curve geometry	29.6%	52.1%	42.3%	60.0%
(10) Present alert of excessive speed for approaching curve geometry	3.7%	2.1%	0.0%	58.5%
(11) Determine driver state	7.4%	100.0%	3.8%	64.6%
(12) Modulate driver control input	63.0%	47.9%	73.1%	83.1%
(13) Present alert of driver impairment	7.4%	100.0%	3.8%	64.6%
(14) Present alert of driver impairment	7.4%	2.1%	7.7%	100.0%
(15) Present warning of excessive vehicle lateral movement	96.3%	95.8%	11.5%	52.3%
(16) Momentary control intervention	96.3%	95.8%	15.4%	100.0%
(17) Safe vehicle attitude	7.4%	100.0%	3.8%	64.6%

The second point that should be noted with respect to Table 5-l is that table distributions indicate a broad utiliition of the functional goals in the four causal factor groups. Specifically, only two cells in the Driver Inattention causal factor group and one cell in the Lost Directional Control causal factor group indicate a lack of applicability of individual functional goals. This broad utilization pattern implies that a countermeasure responsive to the complete set of functional goals would be sufficiently adaptable to alleviate many of the situations which currently result in run-off-road crashes.

A second measure of degree of functional goal efficiency is to determine the average utilization of each goal. This relationship highlights functional goals that are used in limited dynamic situations. Specifically, a low average utilization questions the utility of specific functional goals. This measure is tabulated in Table 5-2 below.

Table 5-2
Average Utilization of Countermeasure Functional Goals

Countermeasure Functional Goal	Average Utilization
(1) Monitor vehicle dynamic status	100.0
(2) Determine geometric characteristics of upcoming roadway segment	100.0
(3) Determine vehicle position/orientation relative to roadway	100.0
(4) Determine driver intentions	100.0
(5) Detect degraded roadway conditions	31.9
(6) Process data to determine acceptable speed for approaching roadway segment	42.2
(7) Detect potential for roadway departure	100.0
(8) Present alert of degraded roadway condition	31.9
(9) Present alert of approaching curve geometry	50.0
(10) Present alert of excessive speed for approaching cure geometry	24.1
(11) Determine driver state	56.0
(12) Modulate driver control input	68.1
(13) Present alert of driver impairment	56.0
(14) Present warning of excessive speed	42.2
(15) Present warning of excessive vehicle lateral movement	65.7
(16) Momentary control intervention	84.9
(17) Safe vehicle attitude	56.0

Examination of Table 5-2 indicates that the two functional goals with the lowest average utilization are those dealing with degraded roadway conditions. To determine the value of these two functional goals, other factors, such as the severity of these crashes, should be examined. Task 1 of this program examined the Fatal Accident Reporting System (FARS) and General Estimates System (GES) to construct a profile of run-off-road crashes. This analysis provided data on crash severity vs. roadway surface condition. This table, originally presented as Table 3-6 in the Task 1 report is reproduced below as Table 5-3.

Table 5-3
Roadway Surface Condition
Fatal Vs. All Run-Off-Road Crashes

Roadway Surface Condition	-Fatal Accident Reporting System		General Estimates System (GES)	
	Fatal Crashes	% of Fatal Crashes	All Crashes	% of All Crashes
Dry	10,867	81.4	766,444	63.6
Wet	1,964	14.7	272,855	22.2
Snow/Slush	145	1.1	31,344	2.6
Ice	245	1.8	98,771	8.2
Sand/Dirt/Oil	17	0.1	5,004	0.4
Other	32	0.2	7,432	0.6
Unknown	77	0.6	23,981	2.0
Total	13547	99.9	1,205,831	100.0

Table 5-3 illustrates that the adverse condition functional goal could prevent or reduce the severity of 17.5 percent of fatal crashes and 33.0 percent of all crashes. These factors illustrate the utility of the proposed functional goals and justify their inclusion in the final countermeasure.

5.1 Other Factors Related to Functional Goals

The functional goals described in Section 4.0 detect and warn the driver of au impending roadway departure. An issue that must be considered is whether there is sufficient time for the countermeasure to function, that is, for the countermeasure to detect the potential for roadway departure, to issue a warning to the driver of the impending departure, and to allow the driver to react to prevent the departure. A countermeasure manifesting the functional goals discussed above must respond sufficiently early in the crash sequence to prevent the crash while avoiding the negative side effects associated with early detection and warning. Negative effects that can result from a countermeasure with active control range from driver annoyance due to false alarms to destabilizing control maneuvers if the system triggers inappropriately.

The implementation of the countermeasure for run-off-road crashes relies on a phased response strategy, That is, the countermeasure will respond to a potential roadway departure with the minimum intensity required to prevent the crash. Typical responses range from low intensity alerts that provide information to the driver in a relatively non-intrusive manner, to warnings that provide a more intense feedback to the driver of imminent danger, and then to control interventions that require the countermeasure to perform active collision avoidance maneuvers. This concept is illustrated graphically in Figure 5-l below. This figure indicates that as the time to the crash or to recognition of the precipitating event(s) leading to the crash increases, the intensity of the required countermeasure action decreases. This is symbolized by the decreasing value of the curve with au increase in the time available.

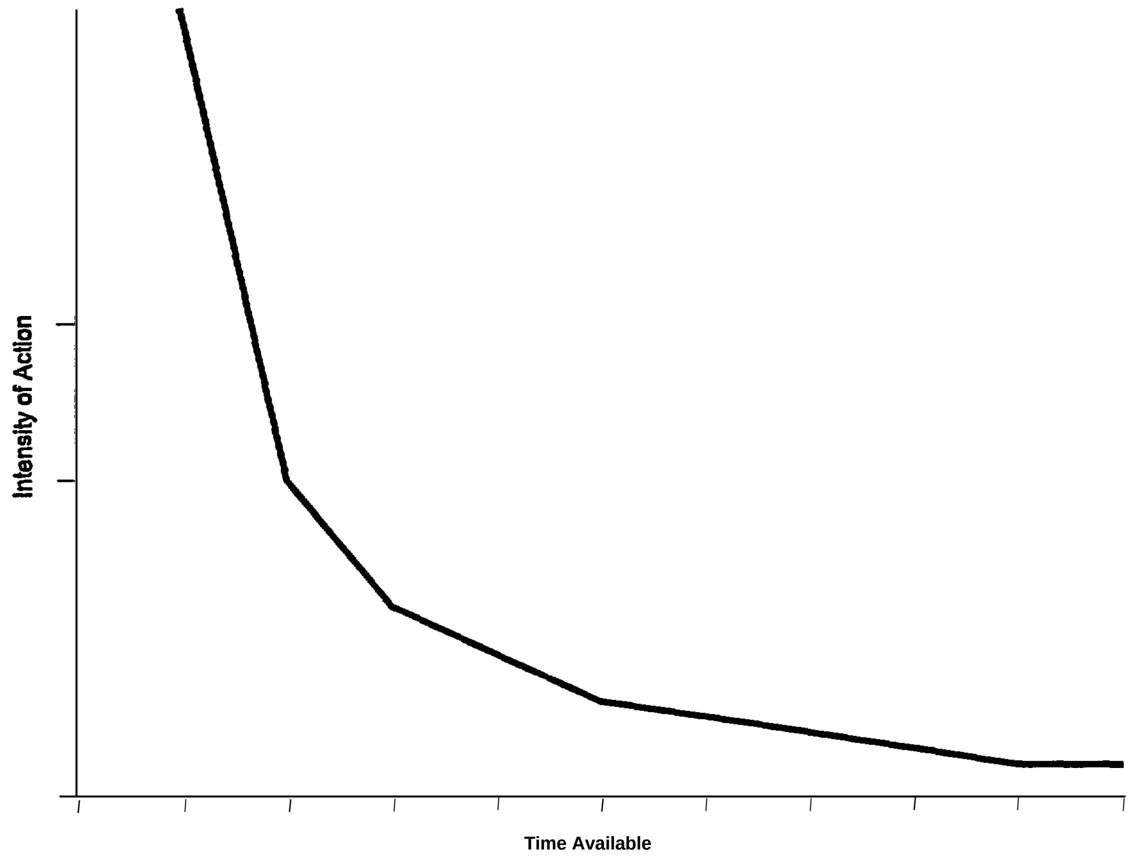


Figure 5-1 COUNTERMEASURE INTENSITY OF ACTION VS. TIME AVAILABLE

The appropriateness of response strategies is dependent upon two factors; the probability that the countermeasure can accurately detect the danger at that particular time and the probability that the particular response strategy being considered would result in a successful collision avoidance. These two factors, in turn, depend heavily upon the characteristics of the countermeasure and the crash situation.

The probability aspects of countermeasure response strategies are addressed in the subsection which follows. The time issue, noted earlier in this subsection, is then more fully discussed in section 5.3.

5.2 Probability of Roadway Departure Prevention for Causal Factor Groups

The probability of roadway departure detection may be expressed for each causal factor group as a graphical representation of the time course prior to each crash event. This method illustrates the probability of:

- The countermeasure detecting the characteristics of the dangerous situation prior to the crash.
- Successful control responses from the driver.
- Successful control response from the countermeasure.

These three probabilities may be used to describe the potential for roadway departure. A discussion of each probability is presented below.

Probability of Detecting: Crash Characteristics

The probability of detecting characteristics that lead to the crash influences the timely presentation of an alert or warning to the driver. These characteristics were determined in the clinical analysis performed in Task 1 of this program. The clinical analysis segregated the characteristics by the primary causal factor noted for each case. Examples of these characteristics are the controlled drift of the vehicle toward the side of the road that exists in the Driver Inattention causal factor group and the loss of driver input to vehicle controls in the Relinquished Steering Control causal factor group. The causal factor groups were used to develop the countermeasure functional goals. This chain of analysis is also appropriate for the definition of other characteristics that lead to run-off-road crashes. The data acquired in Task 3 regarding the performance of existing countermeasure sensing technologies can lead to a definition of the probability of detection of these critical crash characteristics. Due to the preliminary nature of the Task 3 results, the probability of detection curves must be considered approximate. However, we believe that the general shapes of the curves, in the discussions that follow, are correct.

Probability of Successful Driver Response

If the countermeasure has successfully detected the characteristics typical of roadway departure crashes, it would issue either an alert or warning to the driver depending on the immediacy of the threat. The probability of successful driver response curves represent the likelihood that the driver will respond in a manner that will avoid the crash. These curves are based upon Task 1 efforts detailing the typical driver responses prior to and during the crash sequence as well as their effects on the dynamics of the vehicle. These curves do not take into account potential modifications of the driver's response that may occur when the driver is reacting to a warning from the countermeasure. (e.g., startle response or situational assessment prior to the action). Data of this type may be obtained during the performance of the simulator study conducted in Task 3. We believe that these curves are reasonable initial representations of the effects of driver responses on collision avoidance likelihood prior to the crash.

Probability of Successful Control Intervention Response by Countermeasure

These curves represent the probability that the countermeasure could successfully provide control responses to avoid the roadway departure. These curves are in all cases at least equal to, or greater than, the corresponding curves for successful driver response. This reflects the assumption that in all cases, once the characteristics of the roadway departure are identified, the countermeasure could provide control responses that are at least as appropriate for keeping the vehicle on the roadway as those provided by the driver. In many situations, the countermeasure's response may be more appropriate than the driver. An example is the reaction by the driver in those situations where the driver falls asleep at the wheel. In a significant portion of the cases, the driver wakes when the vehicle has left the road, but before impacting any object. The driver will in many cases input a steering correction to return the vehicle to the roadway. This action frequently causes a loss of vehicle stability, making a recovery from the roadway departure difficult. The countermeasure, however, may modulate the driver's input to reduce the magnitude of the steering input, thereby allowing the vehicle to maintain stability and successfully return to the roadway.

It must be noted that the assumptions made in this category, such as modulation of steering input, would not apply to countermeasures designed to prevent roadway departure crashes associated with evasive maneuvers by the driver. In these cases, the appropriate response would not necessarily be to remain on the roadway. This type of crash scenario was eliminated from consideration in Section 4.0 due to duplication of effort with the Rear-End Collision performance specification program.

5 .2 .1 Probability Analysis of Causal Factor Groups

The following section examines the individual circumstances associated with each of the four causal factor groups under consideration. A graphical representation of the potential for collision avoidance is provided and implications with respect to the performance of the countermeasure are discussed.

5.2.1.1 Driver Inattention Causal Factor Group

Crashes associated with Driver Inattention are very difficult to detect prior to the precipitating pre-crash event. In many of these crashes, the driver is in-control of the vehicle and does not exhibit preliminary behavior that would allow the countermeasure to be prepared to react to the roadway departure. Figure 5-2 illustrates the probability of successful prevention of crashes associated with Driver Inattention. As may be observed in this figure, the potential for the countermeasure to detect the danger of the roadway departure is very small until the precipitating pre-crash event, which is typically the point at which the driver becomes distracted. Prior to this event, the driver is driving normally and there is no firm basis for predicting an upcoming roadway departure. This is illustrated by the solid curve in the figure. As the precipitating pre-crash event approaches, the probability of the countermeasure detecting the potential departure increases. This increased probability of detecting the roadway departure risk could be accomplished in several ways. It may result from direct driver monitoring (e.g., an eye tracker that detects that the driver is not focusing on the roadway) or it may result from monitoring the vehicle's position and trajectory on the roadway.

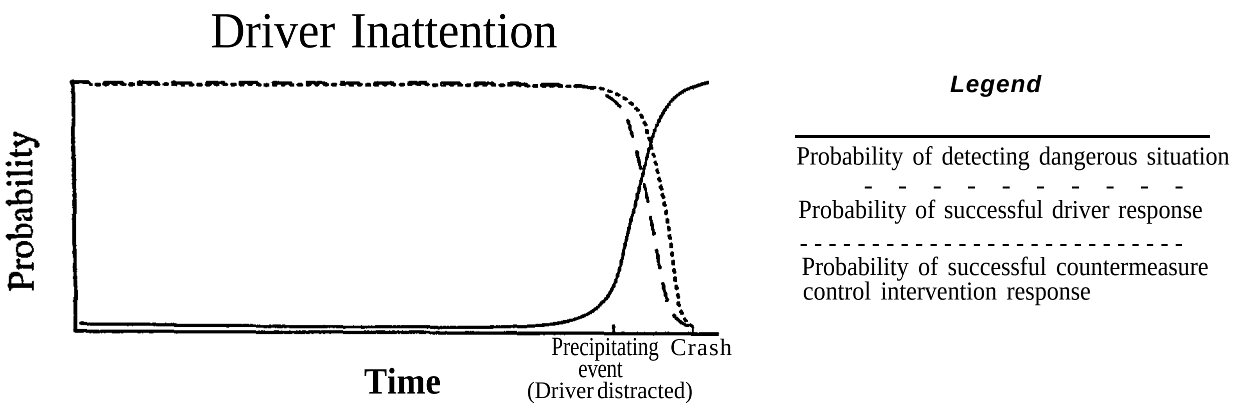


Figure 5-2 DRIVER INATTENTION PROBABILITIES

The probability of the driver successfully responding to an alert or warning is illustrated by the dashed curve. As may be observed in the figure, this probability is equal to the probability of the countermeasure responding successfully (illustrated by the dotted curve) until a time after the precipitating pre-crash event. At that point the probability of the driver successfully responding to the alert or warning drops quickly. In contrast, the probability of the countermeasure successfully responding remains high for a significantly longer time prior to the crash. The countermeasure's response provides a higher probability of crash avoidance than the driver's response after the point of driver distraction since the countermeasure will not overreact and provide inappropriate control input, as the driver often does after refocusing attention on the driving task. This additional time is the margin of safety that the countermeasures supplies to the driver. This margin is enhanced by the ability of the countermeasure to determine the characteristics of a roadway departure event in advance of the vehicle actually leaving the roadway. Of course, immediately prior to the crash, no response from the driver or countermeasure can prevent the impending event. This inevitability is illustrated by the curves, representing the probability of successful response by the driver and countermeasure, decreasing to zero as the crash approaches.

An effective countermeasure for crashes caused by Driver Inattention must be able to recognize characteristics that typically lead to these crashes and issue an alert or warning to the driver. In the countermeasure's favor, however, is the fact that road conditions in which Driver Inattention crashes occur are typically benign and that the time between the point at which the driver is distracted and the crash itself is relatively long. In addition, the driver is alert (although attention is diverted from the driving task). Therefore the driver's ability to make control inputs to recover from the road departure is not impaired. These conditions suggest a relatively high likelihood that an urgent audible or haptic warning soon after the onset of the precipitating event could draw an appropriate response from the driver. Some modulation of the driver's response may be required to maintain vehicle control. In those cases where the driver does not respond to the warning, a timeline analysis of these crashes indicates that there should be sufficient time available to trigger a controlled countermeasure response to prevent the crash. These timelines will be discussed in greater detail later in this section.

5.2.1.2 Relinquished Steering Control Causal Factor Group

The Relinquished Steering Control causal factor group is characterized by the driver failing to exercise vehicle control due to physical impairment. The source of this impairment may range from the driver falling asleep to the driver losing consciousness due to alcohol consumption. Drivers who exhibit these characteristics generally do so over a period of time. It is this time period in which the countermeasure must be able to detect and monitor the driver's vehicle control behavior. There is a reasonable likelihood that the countermeasure could detect the driver's degraded state early in the pre-departure sequence. This is illustrated in Figure 5-3 by the solid curve. As the driver loses consciousness (the precipitating pre-crash event), the probability of the countermeasure detecting the dangerous situation rises quickly to unity. Means by which the countermeasure could detect a driver's degraded state are: driver lane keeping performance, velocity keeping performance, and steering correction magnitude and frequency. If a driver's degraded state is established early in the crash sequence, the countermeasure could provide an alert to inform the driver of this degraded ability and to suggest appropriate action (pull off the road).

The probability of the driver successfully responding to an alert or warning is moderately high prior to the precipitating event. After the precipitating event, in this case the driver's loss of consciousness, the probability drops to zero. If the driver fails to take preemptive action to prevent the crash, such as by pulling off the road, the countermeasure may attempt to issue a warning of a severe degradation of vehicle control. This warning may be accompanied by momentary control intervention through the steering, throttle, or brakes. The probability of the driver successfully responding to the alert is illustrated in Figure 5-3 by the dashed curve.

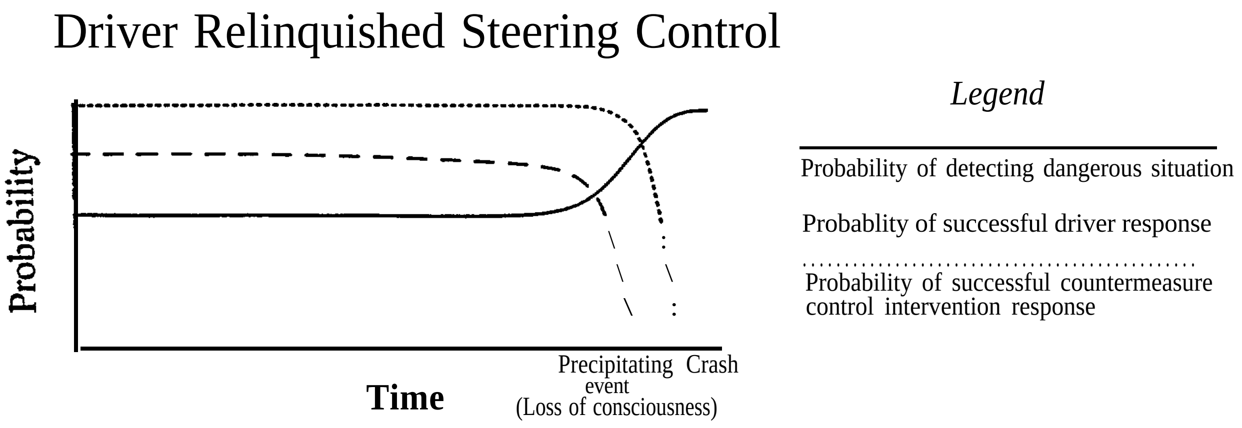


Figure 53 DRIVER RELINQUISHED STEERING CONTROL PROBABILITIES

An additional countermeasure function may be exercised in situations where the driver does respond. In many cases where the driver regains consciousness, the first action may be an excessive control input such as "sawing" at the steering wheel in an attempt to regain control. In these cases, the countermeasure would work to modulate the inputs of the driver to maintain vehicle stability and ensure recovery back onto the roadway.

These actions by the countermeasure are illustrated in Figure 5-3 as the dotted curve. This plot indicates that there is a high probability the countermeasure could detect the impaired driver state in advance of the precipitating pre-crash event and react appropriately to prevent the crash. The sequence of functions implied by Figure 5-3 contain a strategy of phased responses that the countermeasure would use to prevent the crash. This strategy may be summarized as follows:

- Provide the driver with an alert if the danger may be detected with a high probability significantly before the precipitating event is encountered.
- Provide the driver with a warning when the precipitating event is imminent or just after it has occurred.
- Provide momentary control input intervention to avoid the immediate danger of a crash.
- Modulate the driver's response to the alert or warning to insure an appropriate recovery maneuver.
- Safe the vehicle by removing it from the traffic stream if the driver does not respond to the alerts and warnings.

The successful application of this strategy could lead to a significant reduction in the number and severity of roadway departure crashes.

5.2.1.3 Lost Directional Control Causal Factor Group

Many of the crashes in the Lost Directional Control causal factor group are the result of the driver not adjusting, or not adequately adjusting, the vehicle's travel speed. The probability of preventing these crashes is significantly enhanced if the precipitating pre-crash event, typically loss of traction, is detected sufficiently early in the crash sequence. Sensors, located either on-board the vehicle or in the infrastructure could detect the conditions that typically occur with these loss of traction crashes.

If these conditions are recognized by either the driver or countermeasure early in the crash sequence, both the driver and countermeasure have a reasonable potential to avoid the crash. The countermeasure, upon detecting these conditions, would use the least intrusive response to prevent the crash. This response may take the form of an issued visual or audio alert of degraded roadway conditions. The potential success of the countermeasure and driver are related in Figure 5-4. The probability that the countermeasure can detect the conditions responsible for the loss of control is only moderate. This moderate probability is due to the difficulty of detecting a degraded roadway condition prior to the vehicle actually encountering the condition. Following the encounter, it typically is very difficult for the driver to recover. This fact is reflected in Figure 5-4 by the drop in the driver's probability of successful response at the time of the precipitating pre-crash event. Due to these circumstances, a countermeasure that could modulate the driver's response, or provide active control intervention, would provide a somewhat higher probability of avoiding the crash. This is reflected in Figure 5-4 by the dotted curve. In this causal factor group, it is apparent that after the precipitating pre-crash event, the countermeasure has a much higher probability of recovering vehicle control than the driver. Of course, at some point just prior to the crash, neither the driver or an active countermeasure have sufficient time to provide an effective response to the circumstance and the crash is inevitable. This is illustrated by the probabilities of successful driver and countermeasure responses dropping to zero in Figure 5-4.

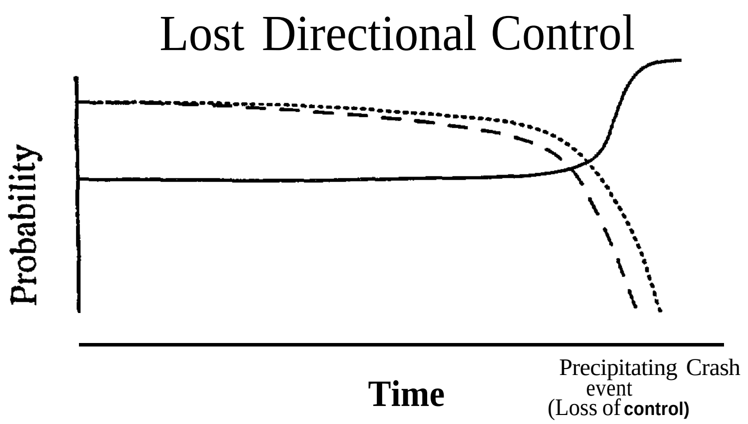


Figure 5-4 LOST DIRECTIONAL CONTROL PROBABILITIES

5.2.1.4 Vehicle Speed Causal Factor Group

In many respects, the crashes in the Vehicle Speed causal factor group resemble those associated with the Lost Directional Control crashes. In these crashes, there is a relatively high probability of the detection of danger, which rises steadily as the vehicle approaches the precipitating pre-crash event. Typically, the precipitating pre-crash event is the driver negotiating a curve. The probability of detecting the dangerous condition is initially only moderate due to the fact that although the vehicle's speed is readily determined by the countermeasure, vehicle speed in itself is insufficient to determine if the situation is dangerous. A vehicle traveling 10 mph above the speed limit on a straight roadway segment is not necessarily dangerous. If this vehicle encounters a curve with this excess velocity, however, the danger increases. The countermeasure would detect the excess velocity, the approaching curve, and issue a alert to the driver. The probability of the countermeasure detecting the dangerous condition is related in Figure 5-5 as the solid curve. The probability remains moderate until the approaching curve is detected and then rises quickly.

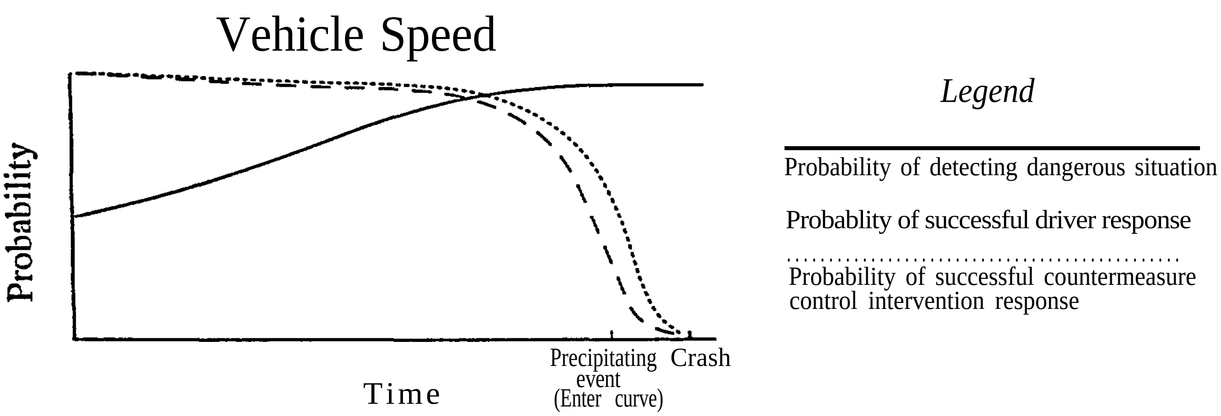


Figure 5-5 VEHICLE SPEED PROBABILITIES

As in the Lost Directional Control causal factor group, the probability of the driver and countermeasure successfully responding is equal until a point just prior to the precipitating pre-crash event. The two curves diverge just prior to the precipitating event in recognition of the ability of the countermeasure to modulate vehicle control in a more appropriate manner. In many cases, the driver will react to the approaching curve by over-reacting, either by applying the brakes in an aggressive manner or by braking and attempting to steer into the curve. In many cases, these actions result in a loss of vehicle stability and subsequent involvement in a crash.

The countermeasure would prevent this crash by issuing an alert to the driver of the dangerous combination of vehicle speed and the approaching curve. If no response is received from the driver, in the form of a reduction in vehicle speed, the countermeasure would issue a warning to the driver. The warning would be more intrusive than an alert to indicate the seriousness of the situation. If the driver does not respond to the warning, the countermeasure would provide momentary control intervention in the form of a pulsing of the vehicle's brakes. Further control intervention could include modulation of the driver's control inputs. As discussed in the Lost Directional Control causal factor group, there is a time prior to the crash where neither the driver or a countermeasure can prevent the crash. This point should not be reached if the countermeasure is operational and effective.

5.3 Time Available for Countermeasure Functions

The total time frame between the point where the subject vehicle begins moving from its pre-crash travel lane position and the off-road point of impact is important to the form and effectiveness of the countermeasure developed for this program. Before discussing the implications of this time frame, however, it would be beneficial to clarify the blocks of time which comprise this time frame. The roadway departure times discussed in Section 3.0 were computed between the point where the subject vehicle begins moving from it pre-crash travel position and the point where the subject vehicle departs the roadway. The point where the subject vehicle begins moving from its pre-crash travel position roughly corresponds to the precipitating event location referenced in the probability discussion presented earlier in this section: (NOTE: In reality, the precipitating event occurs a short time before the vehicle begins moving from its pre-crash travel position.) The point at which the subject vehicle departs the roadway is defined as the critical event location. Thus, the roadway departure times discussed in Section 3.0 correspond to the time frames between the precipitating event and the critical event. The second block of time of interest is the time between the critical event (roadway departure) and the off-roadway crash event. These two time blocks comprise the total time frame between the precipitating event and the crash event.

As indicated previously, the total time frame and the individual blocks of time (as defined above) available for crash avoidance proposes are important to the form and effectiveness of the countermeasure developed for this program. These time frames are examined in this section and specific implications of the individual time blocks and the total time frame are addressed. Primary emphasis is placed on the time available between the critical event and the crash event and the implications of this time block. Evaluation of the total available time frame is provided subsequent to this discussion.

The time available between the critical event to the crash event is important since relatively long time frames imply that a countermeasure operating primarily as a warning device may be practical and effective. Conversely, if a time analysis indicates a predominance of short time frames (e.g., time frames which are smaller than the intervals required by the general population to effectively react), then effective countermeasure designs may require an active control component and/or a predictive component. A predictive countermeasure component would merely require that the system operate in the time interval between the precipitating event and the critical event and successfully predict the impending roadway departure. This implication is not a major difficulty in that most of the preceding discussion related to functional goal application has assumed that this predictive component will be required.

5.3.1 Time Frame Between the Critical-Event and the Crash Event

As discussed in previous sections, during the course of the Task 2 effort, timelines were developed for cases in the clinical sample where sufficient physical evidence was present to support required computations. This effort produced timelines for 102 of the 201 NASS CDS cases contained in the clinical sample. One very useful attribute of the timelines is that it is possible to examine finite time blocks within each timeline. Using this attribute, the project staff segregated the time frames between the critical event and the crash event for each of the cases with timeline reconstructions. These data were then aggregated by causal factor group. Mean time values for each applicable causal factor group are provided in Figure 5-6.

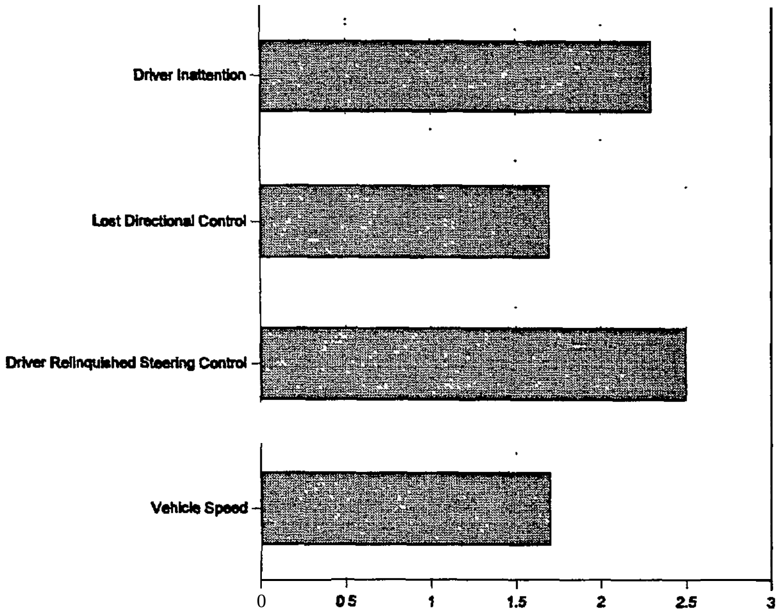


Figure 5-6 MEAN TIME AVAILABLE FROM CRITICAL EVENT TO CRASH EVENT

As evident in the figure above, the causal factor groups with the shortest available times are the Vehicle Speed and Lost Directional Control groups, with mean values of 1.7 seconds. The Driver Inattention and Relinquished Steering Control groups have mean times that are substantially longer with values of 2.3 and 2.5 seconds, respectively. The relative values for these causal factor groups are not unexpected. The event sequence for the Driver Inattention and Relinquished Steering Control groups lead to the vehicle exiting the roadway in a low angle drift. This contrasts with the two other groups where the vehicle leaves the roadway in a sudden manner and at a larger departure angle. The low angle departures, associated with the Driver Inattention and Relinquished Steering Control groups, increase the time interval from the departure point to impact. To clearly illustrate these relative times intervals, the ranges for each causal factor group are provided in Table 5-4.

Table 5-4
Critical Event to Crash Event Times
for
Causal Factor Groups

Causal Factor Group	Critical Event to Crash EVent Time (Seconds)			
	Minimum	Maximum	Mean	Standard Deviation
Driver Inattention	0.1	5.5	2.3	1.5
Relinquished Steering Control	0.1	6.7	2.5	1.8
Lost Directional Control	0.3	4.7	1.7	1.3
Vehicle Speed	0.1	5.2	1.7	1.3

Each of the causal factor groups tabulated in Table 5-4 has a substantial range of times from the critical event to the crash event. A substantial portion of the variability in these times is due to variations in the proximity of appurtenances to the roadway edge. Table 5-5 provides a more detailed view of the distribution of the times for each of the causal factor groups.

Table 5-5
Distribution of Time
Between
Critical Event and Crash Event

Causal Factor Group	Time-to Crash Range (Seconds)							
	0.1-1.0	1.1-2.0	2.1-3.0	3.140	4.1-5.0	5.1-6.0	6.1-7.0	Total
Driver Inattention	17.6	41.2	5.9	17.6	11.8	5.9	0.0	100.0
Relinquished Steering Control	18.5	40.7	7.4	11.1	11.1	7.4	3.7	100.0
Lost Directional Control	33.3	33.3	25.0	0.0	8.3	0.0	0.0	100.0
Vehicle Speed	32.3	38.7	12.9	9.7	3.2	3.2	0.0	100.0

The majority of data in Table 5-5 reside in the 0.0-2.0 second range. This fmding will impact the effectiveness of countermeasures that only alert or warn the driver and require the driver to respond appropriately. The next section compares the time available between the critical event and the crash event with the time that could typically be expected for a driver to execute an effective collision avoidance maneuver for each causal factor group. This comparison will provide further insight into the appropriateness of the functional goals presented earlier, given the time available.

5.3.2 Countermeasure Time Budget

The time required by the driver to execute an effective collision avoidance maneuver can be broken into components, as illustrated by the following equation:

$$MET = RT_{countermeasure} + RT_{driver} + RT_{vehicle}$$

where:

MET	=	Maneuver execution time
$RT_{countermeasure}$	=	Time for countermeasure to detect danger and provide driver with alert/warning
RT_{driver}	=	Time for driver to recognize alert/warning and begin control input to avoid the crash
$RT_{vehicle}$	=	Time for vehicle to respond to control input

For countermeasure to be effective in a particular situation, the maneuver execution time *(MET)* must be less than the time available before the crash, as reported in Table 5-5. A key component of this equation is RT the time required for the driver to react to the warning and begin the corrective control input. If RT_{driver} is not significantly less than the time available before the crash, the countermeasures will not provide a warning in time for the driver to successfully avoid the crash.

5.3.2.1 *Driver Reaction Time*

The reaction of the driver to various situations has been studied for many years. Many of these efforts have dealt with observation of driver reaction times in tightly controlled experimental situations. The inclusion of a countermeasure into the driving equation requires additional tasks of the driver. These tasks include recognition of the meaning of an alert or warning presented by the countermeasure and response to the countermeasure in a "correct" and timely manner. The recognition of an alert requires that the message presented by the countermeasure be familiar to the driver, clear, and concise. Questions relating to the driver's response to a presented warning have not been explored in sufficient detail to allow definitive data to be assembled. The efforts of the project staff in the Iowa Driving Simulator (IDS) are an attempt to provide this additional data for the data file.

5.3.2.1.1 Driver Reaction Times - Brake Application

In the run-off-road departure cases examined, the predominant driver actions were to apply brakes or to input steering maneuvers. Data are available in the literature regarding typical times for these two actions. The most appropriate braking reaction time data for evaluating collision avoidance countermeasures are provided by studies of driver braking responses in collision avoidance situations. Sivak et. al (1992) recorded surprise reaction times for unalerted drivers who were following a lead vehicle whose driver unexpectedly applied brake input. This study recorded 1,644 data points and recorded brake times that were generally less than three seconds. Specifically, 72 percent of the drivers responded within three seconds. The mean value of these data was 1.21

seconds with a standard deviation of 0.63 seconds (Taoka). It should be noted, however, that Forbes (1 994) compiled data indicating that brake reaction times can vary widely depending upon specific circumstances. These data are provided in Figure 5-7 which compiles data for both alerted and non-alerted drivers.

5.3.2.1.2 Driver Reaction Times - Steering Input

The driver's reaction time to initiate steering corrections was examined by Malaterre and Lechner in 1990. These data were generated in the Daimler-Benz simulator in West Berlin. The test utilized 49 subjects traveling on a simulated trip through open country over various sections of straight and winding roadway at travel speeds between 90- 100 km/hr. After about 10 minutes driving time, the subject vehicle approached a four-legged intersection in open country that was controlled by stop signs. Surprisal steering reaction times for 14 subjects were defined as the reaction times to initiate steering away from another car in the intersection. The mean steering reaction time was 0.82 seconds with a standard deviation of 0.24 seconds.

Other studies have used different methods and independent variables, leading to somewhat different results. Summala (198 1) indicated steering reaction times with a mean value of 1.5 seconds to swerve away from a parked car whose door suddenly opened. Together these steering reaction time studies support a similar conclusion to the braking studies; driver reaction times can vary substantially depending on the driver and the circumstances, but they are typically in the range of one second.

5.3.2.2 Implications for Driver Reaction Times

Driver reaction studies indicate that typical driver reaction times for both steering and braking are substantially below the mean time available between road departure and the crash event for each of the four causal factor groups, as reported in Table 5-4. This would appear to support the conclusion that a countermeasure that warns the driver of roadway departure danger once the vehicle has departed the roadway could effectively prevent a substantial number of crashes.

However, several factors would tend to reduce such a system's effectiveness. First, these reaction time estimates are for alert, unimpaired driver. While this is typically the case for the Driver Inattention and Lost Directional Control crashes, in nearly all the Relinquished Steering Control crashes and in a substantial proportion of the excessive Vehicle Speed crashes, the driver is impaired. This impairment would almost certainly increase the driver's reaction time, and reduce the effectiveness of a countermeasure that only provides a warning or alert after the vehicle has departed the roadway.

A second factor that would potentially reduce the effectiveness of a post-roadway departure warning system is the difficulty the driver has in providing control inputs that would avoid the crash after the vehicle has departed the roadway. Once the vehicle has left the roadway surface, both steering and braking maneuvers to avoid the crash become more difficult to execute due to the reduced lateral and longitudinal coefficients of friction. Additionally, the appropriateness of the

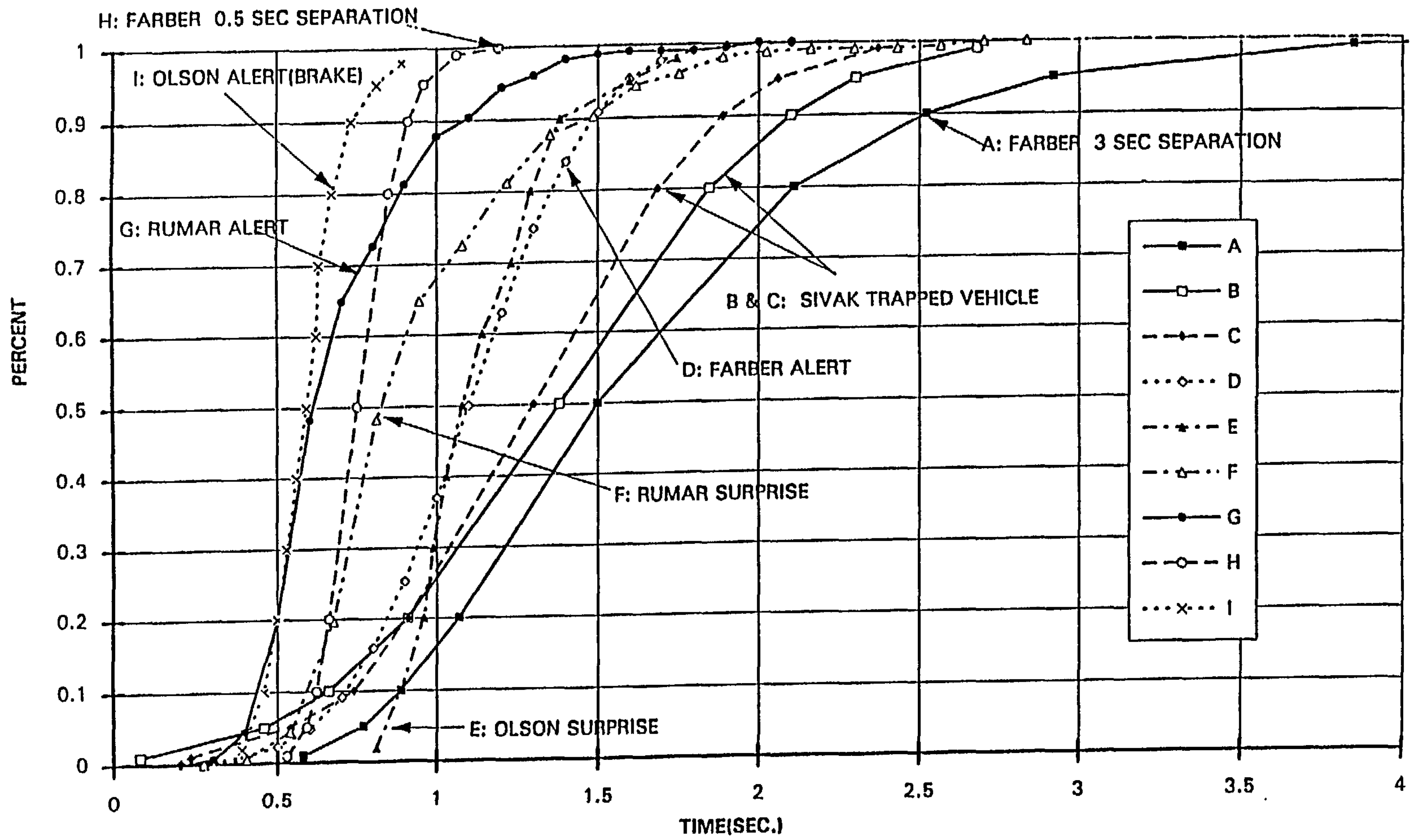


Figure 5-7 BRAKE REACTION TIMES FOR ALERTED AND NON-ALERTED DRIVERS

driver's post departure response is reduced by the startle effect. There was substantial evidence in the Task 1 analysis, conducted for this program, that the surprise a driver experiences upon realizing the vehicle has departed the roadway often causes the driver to overreact and initiate a destabilizing steering or braking response.

The relatively large time required for a driver to react coupled with the difficulty the driver has in providing the correct control response after roadway departure suggest that a countermeasure without a predictive component and/or active control capabilities may be unable to prevent a substantial proportion of roadway departure crashes. This finding suggests that an effective run-off-road countermeasure may need to have a predictive component which operates in the precipitating to critical event time frame and/or the ability to control vehicle functions such as braking and steering. The potential effects of including a predictive component and active control to a roadway departure countermeasure is addressed in the next subsection.

5.3.2.3 Effect of Adding a Predictive Component and Active Control Capabilities

The previous section examined potential performance levels of countermeasures that operate in the time frame between the precipitating event and the crash event. A major finding was that if the point of roadway departure (critical event location) was used as a trigger for issuing a warning to the driver, then substantial portions of the crashes may not be prevented. It is evident that issuing a warning earlier in the crash sequence would allow a more effective system. A countermeasure that could issue a warning prior to roadway departure would provide the driver more time to respond and also would encourage the driver to respond while the vehicle is still on the roadway where control can be maintained in a more precise fashion. This concept must be carefully developed, however, because triggering an alarm prior to the vehicle leaving the roadway could lead to false alarms as the vehicle drifis from side to side in the lane. Practically, this indicates that the countermeasure must determine that a threat exists as the vehicle starts to leave the roadway and that the countermeasure must differentiate this threat from the driver's natural tendency to vary vehicle position within the lane. Although the countermeasure determines that a specific vehicle path will probably result in a roadway departure, an alert to the driver must wait until departure is imminent. During the pre-departure period of time the countermeasure must perform the following actions as necessary:

- Determine the vehicle is about to leave the roadway.
- Issue an alert/warning to the driver.
- Monitor driver response to the alert/warning.
- Determine driver status.
- Determine adequacy of driver response.

To examine the time frame that is available from the point where the subject vehicle begins moving from the center of the lane to the roadway edge, the timelines previously discussed were referenced. These data, originally reported in Section 3.0 as roadway departure times, are recompiled in Table 5-6 below.

Table 5-6
Precipitating Event to Critical Event Time Frames
by
Causal Factor Group

Causal Factor Group	Time To Crash			
	Minimum	Maximum	Average	Standard Deviation
Driver Inattention	0.7	10.3	2.1	2.3
Relinquished Steering Control	0.6	9.0	1.7	1.6
Lost Directional Control	0.5	2.8	1.4	0.6
Vehicle Speed	0.3	2.8	1.2	0.6

As evident in Table 5-6, including the pre-roadway departure will substantially increase the total time frame available to the countermeasure. The full effect is illustrated in Table 5-7 which compiles the available time frames between the precipitating event and the crash event.

Table 5-7
Precipitating Event to Crash Event Time Frames
by
Causal Factor Group

Causal Factor Group	Time To Crash			
	Minimum	Maximum	Average	Standard Deviation
Driver Inattention	0.8	11.9	4.4	2.6
Relinquished Steering Control	0.8	10.1	4.2	2.2
Lost Directional Control	1.1	6.0	3.1	1.4
Vehicle Speed	0.6	7.0	2.8	1.5

Table 5-7 illustrates that the average time available from the point where the vehicle begins deviating from the center of the lane to the crash event would be sufficient to allow an alert driver to respond to a warning and potentially avoid the crash. A more detailed analysis of the distribution of the times between the precipitating and crash events for each causal factor group is provided in Table 5-8 and the discussion below.

For the Driver Inattention causal factor group, Table 5-8 indicates that in 88.2 percent of the cases there is more than two seconds available for the execution of an appropriate avoidance maneuver, Since, the driver in these crashes, is almost always alert and the pavement conditions are